Wave Energy and Actor-Network Theory: The Irish Case

William Cunningham

Autumn 2013

Centre for Technology, Innovation and Culture

William Cunningham

williamcunningha@hotmail.com

University of Oslo

Second Semester Specialisation: Science and Politics in Controversies on Nature

Supervisor: Goran Sundqvist

Word Count: 23374

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Acknowledgments

I am extremely grateful to all those involved in the wave energy sector in Ireland who have helped me during this process. In particular, I would like to give special thanks those who provided many valuable insights by giving up their time and agreeing to be interviewed by me:

Brian Holmes, HMRC

Jochem Weber and Ronan Costello, Centre for Ocean Energy Research at NUI Maynooth

Eamon Ryan, The Green Party

John McCarthy, Ocean Energy Ltd

In addition I would like to give special thanks to Kieran Reilly in the HMRC who has been a valuable point of contact throughout this process.

Biggest thanks of all go to Goran Sundqvist, my supervisor and mentor for this thesis. This work would not be possible without the many valuable insights that Goran provided on a consistent basis. Many enjoyable hours have been spent in Goran's office getting to the bottom of STS concepts and I am very grateful for his enthusiastic input.

Finally, I would like to thank Hege for all the time and patience she has given me throughout the last year.

This is dedicated to our beautiful Daniel.

Abstract

This paper examines the role of the wave energy sector in Ireland using theories from the field of Science and Technology Studies (STS). Theoretical divisions within the field of STS are examined, particularly the Sociology of Scientific Knowledge (SSK) and Actor-Network Theory (ANT). Any conflicts which these two theories present to each other are examined through the empirical findings of the Irish wave energy sector. In particular, ANT's rejection of macro and micro distinctions when analysing society are compared to SSK's identification of causality in the creation of scientific knowledge and technology. ANT's network outlook was later built on by a new SSK concept called 'co-production' and this is also examined in light of empirical findings.

In addition, ANT's theoretical and methodological concepts are applied in the empirical investigations of this thesis. The network approach provides a holistic outlook and helps to explain the various links within the wave energy network. Government White Papers, academic articles, websites and interviews are used in painting a broad picture of the Irish wave energy sector. This is then applied in answering the empirical research question: "What needs to be done in order for wave energy to be successfully implemented in Ireland?"

The use of ANT shows that there are many forces at play in the Irish wave energy network, both positive and negative, and these have been crucial in plotting the path of this young and still developing sector. Empirical findings show that SSK and ANT can both be validated in analysing technological systems.

List of Abbreviations

ANT- Actor-Network Theory

CORES- Components for Ocean Renewable Energy Systems

DCENR- Department of Communications, Energy and Natural Resources

ESB- Electricity Supply Board

EU- European Union

EC- European Commission

GDP- Gross Domestic Product

HMRC- Hydraulics and Maritime Research Centre

IMF- International Monetary Fund

MI- Marine Institute

OEDU- Ocean Energy Development Unit

OWC- Oscillating Water Column

O&M- Operation and Maintenance

R&D- Research and Development

SCOT- Social Construction of Technological Systems

SEA- Strategic Environmental Assessment

SEAI- Sustainable Energy Authority of Ireland

SME- Small or Medium sized Enterprise

SSK- Sociology of Scientific Knowledge

STS- Science and Technology Studies

TPL- Technological Performance Level

TRL- Technological Readiness Level

UCC- University College Cork

WEC- Wave Energy Convertor

Introduction

"The good scrabble player is not the one who uses permutations to get terrific words on his rack, but the one who succeeds in making good placements on the board, even if the words are shorter and less impressive"

From Aramis or the Love of Technology, Bruno Latour, p:99

Since the Industrial Revolution, human beings have made their presence felt on this planet like no other animal. Consumption of resources, pollution and exponential growth have led us to examine the ways in which we, as a species, are impacting, generally negatively, on the natural order of things. One answer to this problem has been technology, specifically in the form of renewable energies. It is thought that the successful development and implementation of wind, solar, and lately wave energy technologies will help us to consume less fossil fuels and, while we're at it, not destroy the apparently fragile planet which we call home.

This thesis is concerned with the development and implementation of wave energy technology in Ireland. The motivation behind this investigation stems from two things. Firstly, the concern for the future health of this planet, and the generations which follow ours, leads to the conclusion that the successful implementation of renewable energies and the gradual easing of reliability on fossil fuels is one of the only sources of hope that the human race has if it wants to preserve its existence. Secondly, the sudden collapse of the Irish economy in 2008 has motivated me to investigate how this small state can capitalise on what is generally regarded as one of the greatest wave resources in the world.

Empirical Background

Ireland is a country of few natural resources. However, it is estimated that the accessible wave energy resource could amount to 21 Terawatt hours (TWh), enough to supply about 75% of the country's electricity requirements as well as providing a valuable indigenous export.[1] At present, like the rest of the world, no wave energy technology is providing electricity to the grid in Ireland. However, there are some signs of technological progress, particularly by Ocean Energy Ltd., a company which will be focussed on in more detail in later parts of this thesis. Wave energy is seen to be relatively benign in terms of environmental impacts and, unlike windmills, there is no obvious social opposition attached to it. Much political and financial support has been provided to the wave energy industry in recent years, most notably when the Green Party was in government from 2007-2011. However, the financial crisis which has enveloped Ireland since 2008 has changed the face of the country and wave energy has been no different to other industries in feeling the impacts of this.

Theoretical and Methodological Background

A presentation of the theoretical and methodological framework for this thesis requires recognition, at the outset, that these two parts are intrinsically linked. This is mainly down to the fact that Actor-Network Theory (ANT) will be used as the main theoretical and methodological framework for the analysis of the wave energy sector in Ireland. As we will see, ANT is a tool for describing how technologies, scientific knowledge and anything else that we are interested in are constructed. It is a means of understanding the things that make up our world today. On the other hand, ANT is also a method. If used in the right,

[1] http://www.seai.ie/Renewables/Ocean_Energy/Ocean_Energy_Information_Research/Irelands_Wave_and_Tidal_Energy_Resources/

simplistic way- “observing and describing” (Venturini, 2009, p: 259) - ANT provides us with a roadmap for understanding how these things are constructed, opening the door for full analysis.

ANT is part of the field of Science and Technology Studies (STS) which refers to a sociological movement which began to question the autonomy of science from the 1960s onwards. This was best exemplified by the field of the Sociology of Scientific Knowledge (SSK) in the 1970s, led by the likes of David Bloor and Harry Collins. Proponents of this theory asserted that science was driven by wider factors in the society within which it existed, thus challenging the notion that science is an autonomous machine revealing truths about nature.

ANT built on SSK but took a sharp turn away by questioning the way that SSK held society up to its own unexplainable level as a means of explaining how scientific knowledge emerges. ANT delved even deeper by wishing to explain those social forces at play in a particular scientific or technological ‘network’. This meant that there was no distinction between science, technology or society, just different actors, all affecting each other in every direction, all being simultaneously produced.

As a means of showing this, proponents of ANT choose to ‘follow the actors’. By focusing on who the relevant actors are when it comes to a particular network, what they are doing and how they are affecting each other, we will gain a deeper understanding of how and why that network is the way it is. Importantly, ANT makes no distinction between human and non-human actors, with both being equally capable of affecting the course of a network.

Research Questions

With these empirical and theoretical considerations in mind, this thesis aims to address two things.

Firstly, the use of ANT will help to answer the following research question:

"What needs to be done in order for wave energy to be successfully implemented in Ireland?"

The ANT approach is such that a broad and holistic perspective is required in analysing technological projects. Because of this, a broad research question is necessary. This leads the investigation of the thesis to actors centrally involved in the Irish wave energy sector. Following a thorough investigation of relevant literature, a series of interviews with these actors attempts to elicit the problems associated with the sector in Ireland, the positive mechanisms in place, the main factors holding it back and, overall, the forces which are dictating the path of wave energy in Ireland. What kind of constraints have the actors encountered on the development of this technological system? Again, following the actors and their actions will show if there is anything holding back the technology under investigation. Are the problems technical or economic? Are we to blame a lack of breakthrough on an inefficient electrical generator or on a change of government? Perhaps both types of factors are to blame. Overall, it is the hope of this thesis that the use of ANT can help in plotting a successful path for the Irish wave energy sector.

Secondly, with a symmetry that will appeal to STS scholars, empirical findings from the wave energy sector in Ireland will help in contributing to the field of STS. Does the development of this technology in this particular context fall in line with ideas from ANT?

Are localised actors the only things that count or can the development of the sector be explained by exogenous social forces, as originally believed by proponents of SSK? Is there evidence of the wave energy sector affecting its surrounding society as that society affects it or is the level of influence unidirectional?

The combination of these empirical and theoretical findings will hopefully contribute to a better understanding of the Irish wave energy sector, satisfying an overall goal of contributing towards the emergence of this young and struggling industry.

Theory and Methodology: Developing an ANT Framework

Theory: A Background in Science Studies

After the Second World War and the destruction imposed on Hiroshima and Nagasaki by the Atomic bomb, there emerged a perception that science could be used to the almost limitless advancement of mankind. Science was seen as an all-powerful element which could reveal truths about nature and the environment which we as humans would, in turn, benefit from. This was exemplified by authors like Polanyi who in his article, *The Republic of Science* in 1962, held science up to an almost deified authority. He spoke about a "dual function of professional standards in science" which was "the logical outcome of the belief that scientific truth is an aspect of reality" and that the orthodoxy of science is taught to novice scientists enabling 'him' "eventually to make his own contacts with this reality." (Polanyi, 1962, p: 59)

Just as importantly, Polanyi was extremely keen to demarcate science from the rest of society, drawing boundaries and not advocating any use of lay knowledge in its advancement. In order to gain access to this technocratic hegemony, and thus the truth about nature, 'young men' would have to go through a process controlled by the already entrenched scientific community. This then would lead them to the ultimate authority:

"Admittedly, the body of scientists, as a whole, does uphold the authority of science over the lay public…And, indeed, the whole outlook of man on the universe is conditioned by an implicit recognition of the authority of scientific opinion." (Polanyi, 1962, p: 60)

This was science in its truest, most idealised form. Provided it remained free of disruptive elements, it would take the place in society as an all-powerful force helping the advancement of the human race.

Polanyi was not alone in his authoritarian view on science. Scholars like Merton also agreed that even though there was sociology in scientific *practice*, scientific *knowledge* was truth in its purest form. This was a view challenged by Thomas Kuhn's, *The Structure of Scientific Revolutions*, which was published in the same year as Polanyi, 1962. Kuhn talked about how science and scientific knowledge took the form of paradigms and paradigm shifts, where the use of various cultural resources was central in the emergence of various forms of scientific consensus. New tools, updated theory and general scientific consensus allowed for the emergence of scientific 'discovery'. When certain 'truths' were deemed wrong by a new discovery or 'anomaly' to the previous consensus, a paradigm shift would take place. According to Kuhn, other social factors aided the uncovering of these anomalies:

"Whatever the level of genius available to observe them, anomalies do not emerge from the normal course of scientific research until both instruments and concepts have developed sufficiently to make their emergence likely and to make the anomaly which results recognizable as a violation of expectation." (Kuhn, 1962, p: 174)

What was crucial in Kuhn's analysis was the recognition of non-scientific factors like hierarchies, negotiations and learning processes in the emergence of scientific 'facts' or 'knowledge'. This was a major shift away from purists like Polanyi and opened science up to a whole new level of thinking. By focussing on what the scientists were doing and how they were producing knowledge, something which would become even more prevalent in later studies of science, Kuhn was demonstrating that there was a sociological back bone and this had a fundamental effect on how science was produced:

"Though awareness of anomaly marks the beginning of a discovery, it marks only the beginning. What necessarily follows, if anything at all is to be discovered, is a more or less extended period during which the individual and often many members of his group struggle to make the anomaly lawlike…While it continues, scientists repeatedly revise their expectations, usually their instrumental standards, and sometimes their most fundamental theories as well. In this sense discoveries have a proper internal history as well as a prehistory and a posthistory.” (Kuhn, 1962, p: 174)

Kuhn’s work was an inspiration to many social scientists and laid the foundations for decades of different theories on the sociology of scientific knowledge, what would later emerge as the field of Science and Technology Studies (STS). It was no longer taken for granted that science was making contact with nature, this shift in focus saw it as a product of social forces:

“… they viewed the social not as a disruptive element needing to be purged from science, but rather as an ever-present, necessary component of scientific knowledge.” (Asdal et al., 2007, p: 13)

Scholars began examining what social factors were at play in the development of scientific knowledge and a few were more influential than others. David Bloor, one of several such scholars from the University of Edinburgh, became a leading figure in the field after his publication of *Wittgenstein and Mannheim on the Sociology of Mathematics* in 1973. What emerged from this paper, and a book saying similar things in 1976, was what Bloor, himself, dubbed the ‘Strong Programme’. This built on Kuhn’s work, and was one of the first papers in what became known as the Sociology of Scientific Knowledge (SSK). Bloor called for the use of symmetry in the analysis of science. What this meant was that both ‘truths’ and ‘falsities’ should be analysed in the same way so that instead of scientific successes being held up as revelations of nature, and failures explained away by social factors, both were susceptible to the same exogenous forces. Bloor broke the ‘Strong Programme’ down into four requirements- causality, impartiality, reflexivity and symmetry- as a means of challenging the realist, rationalist view on science.

Most important for this thesis is the first requirement- causality:

"The first is that the sociology of knowledge must locate causes of belief, that is, general laws relating beliefs to conditions which are necessary and sufficient to determine them." (Bloor, 1976, p: 173)

This was in line with the general consensus of SSK at the time, a consensus which was later challenged by the more constructivist approach of Actor-Network Theory (ANT), in that there was a larger sociological force at play which affected how science took place and how it produced knowledge. Humans, being social animals, were at the centre of this:

"What is seen, heard and touched makes up part of the total causal picture along with the human capacity for processing or failing to process such information." (Bloor, 1976, p: 174)

It was still as a response to realism and teleological explanations that Bloor's programme took as a point of departure but the answer to this problem was, fundamentally, causality:

"To accept Realism as a theory of mathematics will result in the intrusion of a radically different picture of human nature and knowledge into the very centre of the programme. It entails a sudden switch from fully causal to teleological concepts as the sociologist moves across the scheme of human activity from say, ethical and political belief, to mathematical skills." (Bloor, 1976, p: 180)

It was this overarching social force that later approaches took exception to, as we will see with the emergence of ANT. Proponents of ANT felt that SSK was going around in circles by replacing the teleological assumptions of science with similar ones for society. They wanted these sociological forces to be opened up to scrutiny. However, this wasn't necessarily lost on Bloor who was able to explain the larger social force without rejecting its imposing effects on the knowledge being produced:

"There is a sense in which institutions exist in their own right over and above the specific acts of people who play roles within them. This is because institutions involve ways of behaving which have become settled and routinized. Certain ways of behaving have become ingrained in the dispositions of a group of actors and expectations have crystallised." (Bloor, 1976, p: 188)

Following the impact of the 'Strong Programme', scholars of SSK began to look into the actual acts of science and knowledge production. It was felt that by examining the mechanisms at play, particularly in matters of controversy, it could be proven that the social was a decisive force. This was perhaps best encapsulated by Harry Collins and the 'Empirical Programme of Relativism'. By demonstrating what went on in laboratories, Collins was able to demonstrate how 'interpretative flexibility'- differing interpretations of scientific findings- was a factor in the very production of knowledge. This was then followed by 'mechanisms of closure' which were the means to which these various interpretations became solidified as 'facts'. Crucially for this thesis, Collins linked these two mechanisms to the broader social structure, the same 'causality' that Bloor outlined. In writing the introduction to *Stages in the Empirical Programme of Relativism*, Collins described the underlying theme of the papers which made up the empirical programme:

"First, they develop the empirical programme in its sociological details. Second, they contribute to the understanding of the relationship between scientific knowledge and broader social processes." (Collins, 1981, p: 4)

Collins is explicit that wider sociological factors, and not just those actors involved in the localized networks, have influence on that which occurs in those networks. Actors in the laboratories and other centres of knowledge production do what they do based on wider sociological contexts and it is, thus, this wider context which ultimately effects that knowledge. Collins wanted to show with his and other studies of scientific production that "consensual interpretation of day-to-day laboratory work is only possible within constraints coming from *outside that work.*" (Collins, 1981, p: 4)

After the emergence of SSK, as described by Bloor, Collins and others, a new way of looking at the sociology of science emerged. Led by academics from the *Ecole des Mines* in

Paris like Callon and Latour, and John Law from the University of Keele, it was this explanation of science by the larger exogenous social factors which came under scrutiny. Law states this clearly:

"If we want to understand the mechanics of power and organisation it is important not to start out *assuming* whatever we wish to explain. For instance, it is a good idea not to take it for granted that there is a macrosocial system on the one hand, and bits and pieces of derivative microsocial on the other. If we do this we close off most of the interesting questions about the *origins* of power and organisation. Instead we should start with a clean slate." (Law, 1992, p: 380)

Proponents of ANT attempted to deconstruct the social, their crucial turn being that factors like economics, politics and social norms could not be held up alone as explanations for the production of knowledge. Instead, these very factors were constantly being constructed and deconstructed in heterogeneous networks, of which science was also a part, in which no distinction was made between humans and non-humans, nature and culture. These boundaries were considered to be imaginary and it was the roles of the actors in relevant networks, regardless of status, that counted.

"This then is the crucial analytical move made by actor-network writers: the suggestion that the social is nothing other than patterned networks of heterogeneous materials." (Law, 1992, p: 381)

Then what has ANT to say to the fact that there are some factors in society which are stronger than others, which appear to the untrained eye to be entrenched, powerful and influential? Law's explanation, that of 'punctualized resources', is close in its description to Bloor. These larger forces are still heterogeneous networks, maintaining all the characteristics of the actor-network. They are just too well established to be seen as such:

"On the other hand, punctualized resources offer a way of drawing quickly on the networks of the social without having to deal with endless complexity. And to the extent that they are embodied in such ordering efforts they are then performed, reproduced in, and ramify through the networks of the social." (Law, 1992, p: 385)

Even though it is hard to argue with Law's approach which goes on to say that these forces are never permanent and are constantly reproducing themselves, that they are never autonomous, complete or final, there is no denying the *existence* of these forces. What Law is saying is assumed to be correct- these factors are not beyond explanation. As we have seen, Bloor agrees with this. What is important to examine is whether these forces are just another one of the actors taking their place in the heterogeneous network. Or, as the early SSK scholars attested, are they something else, something bigger, something beyond the localised network? Something which can explain much of the nature of that network without that network explaining it? Empirical findings from the Irish wave energy sector will attempt to shed some light on this.

ANT and Co-Production

Just as importantly, and another contention which will be examined in this thesis, was the idea that the forces at play in the network were having effects in all directions. An important part of ANT was the way in which it gave power back to science and technology after SSK had previously invested most of this power in their sociological surroundings. Not only were non-scientific forces affecting the character of science but that same science was, at the same time, affecting the society which surrounded it. This is a fundamental characteristic of ANT. Because there are no boundaries between science and nature, society and culture, etc., the effects of things are multi-directional. It is not enough to say that there is a society affecting a certain kind of knowledge or technology, or even that these are affecting society in the other direction. Rather, these forces are constantly producing each other within the endless, infinite actor-networks that make up our reality.

This is embodied in a concept closely related to ANT called ‘co-production’, which came about through academics with roots in SSK. This was seen as an acknowledgment of ANT’s constructivist approach to wider social forces but also agreed with ANT’s other turn. As scientific and technological processes become entangled in social processes, proponents of co-production concede that it is impossible to merely pander to dominant discourses like economics or politics:

“Briefly stated, co-production is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. Knowledge and its material embodiments are at once products of social work and constitutive of forms of social life; society cannot function without knowledge any more than knowledge can exist without appropriate social supports.” (Jasanoff, 2004, p: 2)

So, according to proponents of this theory, it is not enough to say that one form of science or technology is the way it is because of the nature of the social that affected it. Those very social forces that sociologists try to use as explanations are themselves affected by other forces including the very science or technology to which we are trying to explain:

“Scientific knowledge, in particular, is not a transcendent mirror of reality. It both embeds and is embedded in social practices, identities, norms, conventions, discourses, instruments and institutions- in short, in all of the building blocks of what we term the *social*. The same can be said even more forcefully of technology.” (Jasanoff, 2004, p: 3)

There is almost no difference between this and ANT which also believes in a multi-directional and on-going construction between the different worlds:

“But even if the social and the technical are both taken to be important, there is a third trap to avoid. This is the notion that the technical and the social evolve as a result of separate processes and only subsequently interact. By contrast, our aim has been to suggest that they are *jointly* created in a single process.” (Callon, 1989, p: 296)

From Science to Technology

As outlined above, decades of academic theory and empirical testing showed that there is very little reason to doubt that there is a sociology prevalent in science and scientific knowledge. STS has moved on since the days of disproving scientific realism and now it is the nature of this sociology which is in dispute. As has been briefly alluded to, the very same theories and assumptions that we now make about science are equally valid for technologies. Indeed, Bruno Latour, one of the founders of ANT refused to distinguish between science and technology as he believed each contained many features of the other. To satisfy this, Latour came up with the term 'technoscience' (Latour, 1987, p: 174). Technologies are usually manifestations of scientific 'discovery' and it is assumed that they are open to the same sociological theorizing as science. As Jasanoff said, if science is embodied by the building blocks that we call the social, the same can be said "even more forcefully" for technologies.

The focus on technology was also well embodied in a concept known as the Social Construction of Technological Systems (SCOT). This was close to ANT in principle, mainly because it attempted to explain technological configurations by re-tracing the social forces that contributed towards those configurations:

"One of the central tenets of this approach is the claim that technological artefacts are open to sociological analysis, not just in their usage but especially with respect to their design and technical 'content'." (Bijker, et al. (eds), 1989, p: 4)

Since ANT is going to be the central frame of theory for this thesis, it is important to understand exactly what approach it takes towards technological analysis. A fundamental starting point for this is the understanding in ANT that there is no distinction between human and non-human actors. Both take their places on an equal footing in the networks they are deemed to be making up and both have the potential to effect other 'actors' in that network, or the network as a whole, in the same way. This claim, said by many critics to be de-humanizing, goes hand in hand with general theories on co-production and the rejection of the power of the unexplainable exogenous.

This is a point agreed upon by Callon:

"Yet though sociology and anthropology have played a decisive role by describing the detailed content of scientific practices and have undermined a range of classical assumptions about science, they have unfortunately failed to account satisfactorily for its undeniable influence. This is because they have sought to explain its origins and success in terms of supporting political interests, resources gathered by researchers, or pressures of economic demand. In short, they have searched for the causes of scientific power not within science but rather within the surrounding society." (Callon, 1989, p: 19)

Because the actors are constantly re-defining each other, and no boundaries are assumed to exist between them, a distinction between human and non-human is futile. This means that when carrying out analyses of technological systems, we need to focus on both the technical and social aspects of that system in equal measure. A failing on either side can result in the failure of the system as a whole. As Callon says in his examination of the electric car in France:

"For, if the electrons do not play their part or the catalysts become contaminated, the result would be no less disastrous than if the users rejected the new vehicle, the new regulations were not enforced, or Renault stubbornly decided to develop the R5." (Callon, 1989, p: 22)

Callon and Law reiterate the point in their analysis of the British government's attempt to develop a new fighter airplane:

"This suggestion and the methodological principle upon which it rests lead to a conclusion that is counter-intuitive for many sociologists. This is that we must study not only the social but also the *technical* features of the engineer's work; in other words, we have to understand the *content* of the engineering work because it is in this content that the technical and the social are simultaneously shaped." (Callon and Law, 1988, p: 284)

This was a central part of what Latour was saying in his book about a failed railway system in France, *Aramis or the Love of Technology.* According to Latour, technologies have to interest people and things at the same time, the innovator having to count on assemblages of things that often have the same uncertain nature as groups of people:

"The same sort of involvement that has to be solicited from DATR, RATP[2], etc. now has to be solicited from motors, actuators, doors, cabins, etc…they too have their conditions, they allow or forbid other alliances. They require, they constrain, they provide." (Latour, 1996, p: 56)

This is, according to ANT, the real sociology in technologies. Actors may take their own backgrounds and contexts to the network but it is only what they are doing in that network that affects the path of the technology. Either a non-human component or a human actor can have positive or negative effects, breathing life into the technology or contributing to its demise. These actions are, according to ANT, what matters the most, this is the only sociology. Social conditions which are deemed to be entrenched and pre-existing are a fantasy:

"Once an actor-world comes into being, it does not draw its entities from previously established stock. It is not constituted in the way a shopping cart is filled. In short, there is no world, or worlds, from which pre-existing elements can be extracted." (Callon, 1989, p: 24)

In conclusion, the use of ANT as a theoretical framework means that, after the application of empirical findings in the Irish wave energy sector, the basic principles as described above will be examined. Examination of technologies will attempt to show how their development is intrinsically linked to social forces like financing and politics and how the effects between these forces and the technologies in question are multi-directional. One of the basic differences between ANT and earlier SSK will also be examined- can scientific knowledge

[2] French transport agencies

and technological development be explained, at least partially, by exogenous social forces? Can SSK and ANT principles co-exist? An application of ANT's methods will help to answer these questions. The use of these methods will also contribute towards answering the more empirical questions related to wave energy in Ireland, as set out in the previous chapter.

Method

Because the application of ANT principles is crucial in answering the questions above, a proper ANT methodology is required. This will also provide the framework for answering the empirical research question of this thesis: *"What needs to be done in order for wave energy to be successfully implemented in Ireland?"*

As mentioned above, ANT rejects the pre-supposition that there are larger social forces dictating the path of a technology's development. This leads us to focus almost solely on the local forces around the project, the 'actors' taking part in the 'network', because it is these actors who are having real effects on a project. Law and Callon describe this well:

"There is an old rule of sociological method, unfortunately more honoured in the breach than the observance, that if we want to understand social life then we need to follow the actors wherever they may lead us." (Callon and Law, 1988, p: 284)

By following the central actors in a project, and taking seriously what they are doing or saying, we can see how different forces around a technology are shaping it and defining its very essence. The ways in which different actors act as 'spokespersons' for different interests is crucial to ANT. They will attempt to 'translate' their interests into the technology through a series of 'negotiations'. This is the basic sociology behind ANT- following the actors will, according to ANT principles, lead us to a real understanding of the technology under investigation. This is what Latour describes as a 'refined sociology' (Latour, 1996, p: 131).

With this in mind, the outset of the methodology for this thesis is the identification of actors in the wave energy sector in Ireland. In order to compile a list of actors and identify who the relevant ones are, an extensive knowledge of the wave energy sector is required. This requires a detailed literature review and this is begun in the early part of my investigations. Apart from providing a good base level of knowledge, this literature review enables me to define some problems, builds expectations which can be defied by further empirical research, and puts me in touch with theories in the field (McCracken, 1988, p: 31). On the other side, special care is taken to approach the literature review in a critical manner, always bearing in mind the positions and potential motivations of those writing the articles under review. An uncritical perspective could lead to the possibility of taking some of the findings of the literature review for granted and the building of some preconceptions so a balance is required at this stage.

To begin with, academic articles are examined. These reveal a small amount of articles on wave energy and an even smaller number which are focussed solely on the situation in Ireland. Nonetheless, these articles are read in detail, giving a good foundational knowledge to the investigator. In addition, it is easy to see from the articles that those actors engaged in releasing academic work around the sector are small in number and belong to one of two institutions in Ireland.

Once on the path of investigation, the level of material available increases exponentially. Two companies involved in the development of wave energy devices are identified as leading actors in the Irish sector. Extensive consultation of their own web-sites reveals their locations, details about their technologies and an overview of their histories. Primary documents are also found. These vary in nature and usefulness. Government white papers provide an excellent overview of the sector and reveal official plans for the future of the industry. A scoping report for a Strategic Environmental Assessment (SEA) for a wave energy test site is similarly useful. Various brochures, presentations, guidelines and articles are consulted and by the end of this first phase, a clear idea of the sector and of who the relevant actors are has been developed.

The approach to this phase of the thesis is agnostic in nature. This fits in well with ANT which emphasises the actors in the network as the most relevant factors:

“This rule of method, then, asks us to take seriously the beliefs, projects, and resources of those whom we wish to understand.” (Callon and Law, 1988, p: 284)

Any pre-suppositions would skew this line of investigation as it is the ultimate goal of the research to gain these perspectives in as pure a form as possible. This fits in well with the ‘qualitative’ form of social research which provides another loose frame of reference. Approaching the investigation with a pre-ordained research question would narrow the scope of the research. Vital things that are currently relevant, things which are now concerning the actors could be easily overlooked if the research is dedicated to one specific line of investigation:

“It is impossible to decide which bits of evidence about a case are relevant without clarifying the concepts and ideas that frame the investigation. The initial goal of knowing as much as possible about a case eventually gives way to an attempt to identify the features of the case that seem most significant to the researcher and his or her questions. This shift requires an elaboration and refinement of the concepts that prompted the study in the first place or the development of new concepts.” (Ragin and Amoroso, 2011, p: 115)

Interviews

Following the development of a basic and widespread understanding of the wave energy sector, it is time to go a little deeper. Although a literature review will provide a good base, it is important to get as close to the actors as possible. By interviewing those identified as relevant to the sector and, more specifically, the technology, the investigation will be framed by those actors:

"How to frame a technological investigation? By sticking to the framework and the limits indicated by the interviewees themselves." (Latour, 1995, p: 18)

Over the course of the third month of the investigation, attempts are made to make contact with some of the desired actors. This is initially done through email with the message indicating the content of the Masters programme being undertaken, an overview of the investigation, the reason that actor is relevant and a request to set up an interview. These early attempts are, in general, met with a lack of response. Nonetheless, persistence in the form of more emails and some phone calls over the next couple of months leads to the successful undertaking of a number of interviews.

Preparation for the interviews is based on a few factors. To begin with, knowledge gained from the literature review forms the basis of the framing and construction of the interview questions:

"It begins to establish the domain the interview will explore. It specifies categories and relationships that may organize the data. It helps to indicate the larger factors that direct respondent testimony. It helps to determine what the respondent should ask about and what he or she should listen for." (McCracken, 1988, p: 31)

Just like the approach to the literature review itself, though, special care is taken not to allow perspectives gained from the literature review by the investigator to drive the interview conversation too much. Keeping in line with the ANT approach, it is kept in mind that the actors under investigation are the ones who should ultimately dictate the direction of the conversation. It is their perspectives, their worries and their expectations which are of value and so the previously established agnostic approach is maintained during the course of the interviews. Conscious efforts are made during the course of the interviews to allow the subjects to dictate the direction as much as possible. As this happens, the framework of questioning evolves, constantly reacting to the things laid out by the subjects. This is 'following the actors' in its true form.

Questions during the interview process are kept as open and general as possible. For example, a question such as "Can you tell me what you see as the main problems in the wave energy sector?" will lead to a much more relevant response from the subject than "How has the poor financial climate influenced the wave energy sector?" It is the main goal of this part of the investigation to encourage the subject to continue to speak as much as possible, expanding on his or her line of thought. Thus, efforts are made to interrupt the subjects as little as possible, as well as encouraging them to continue their lines of speech with one word encouragements like "Yes" and "OK".

On some occasions, it appears that subjects are reluctant to talk about topics deemed important by the investigator going into the interviews. This is usually when subjects are asked about specific technological developments, a topic they deem either too complex for this kind of investigation, or something which needs to be protected from the public domain. As a result, any deficits are filled in through information garnered from academic articles and other written sources.

Throughout all interviews a dictaphone is used to record proceedings. On a basic level, this means that it is not necessary to write notes recording what is said. The only time notes are taken is to record certain facial expressions or body language which are not obvious from listening to the tape. Following the interviews, full transcripts are typed out. McCracken (1988, p: 41) recommends this to be undertaken by a professional transcriber so as to avoid familiarity of the data that does not serve the later process of analysis. This is beyond the means of the investigator and it is found that the transcription process serves to benefit the research as it provides a good insight into the interview and helps to identify some of the important things that may not have been picked up on during the process. Further reading of these transcripts leads to the important process of analysing the interview findings. This involves the exhaustive process of deciding which data is relevant to the thesis and which needs to be left out. By this stage, the broad, agnostic approach with no specific research question has been replaced by a more specific direction. The interview transcripts now form a crucial part of the empirical body of the thesis and are set in the context of the literature review previously undertaken as well as the theoretical questions posed in the previous chapter.

For some of the actors, privacy is an issue. Despite all of the actors agreeing to allow their names to be used in the thesis, one actor requests the transcript of his interview to be sent to him first as well as the guarantee that it will not be available in the public domain. Another actor requires a non-disclosure agreement to be signed before the interview. Both of these requests are consented to.

Technological Actors

As has been mentioned a few times already, one of the key things setting ANT apart from other STS theory is the refusal to separate human and non-human actors when analysing scientific or technological artefacts. Both have agency and both affect the course of a technological development. As sociologists, we must understand the technological configuration of an artefacts as this will, in theory, contribute towards revealing the social forces at play in that very configuration:

"This is that we must study not only the social but also the *technical* features of the engineer's work; in other words, we have to understand the *content* of the engineering work because it is in this content that the technical and the social are simultaneously shaped." (Callon and Law, 1988, p: 284)

As this investigator comes from a non-technical background with no previous knowledge of hydraulics, turbines, mooring devices, or anything else relevant to the complicated machines that are wave energy convertors (WECs), this is one of the most challenging aspects of the investigation. This can also be viewed in a positive way, though, a lack of theoretical preconceptions allowing me to continue my agnostic approach to the subject. Initial optimism rests on the hope that interviews with the actors will make this a much easier process. Questions are put to interview subjects in the hope of eliciting the technological configurations in layman's terms but, as mentioned above, this was mostly met with reluctance. As we will see later in the thesis, what the actors involved in technological development are most interested in are, in fact, the *processes* involved in developing the technologies. Keeping in line with ANT principles, this line of inquiry is followed up vigorously. Nonetheless, a good understanding of the technological configurations is still required and anything not gained from interviews is filled in through the reading of technical articles.

Summary

In summary, an examination of the theoretical and methodological principles of ANT has laid the foundations for further empirical investigations in this thesis.

To begin with, ANT says that in order to understand a technological project, a good understanding of all actors- human and non-human- affecting that project needs to be gained. This is achieved through a comprehensive literature review and a series of interviews with key actors within the Irish wave energy sector. The following of ANT's methodological principles will help to answer the empirical research question of this thesis as well as providing the framework for the examination of STS theories from the perspective of the Irish wave energy sector.

Wave Energy: History, Organisation and the Irish Case

The idea of extracting energy from the vast movements of the oceans has been prevalent for decades. It is estimated that between 1856 and 1973, over 340 British patents were granted to companies attempting to utilise this resource (Leishman & Scobie, 1976, p: 6). Indeed, many of the basic concepts for carrying this out are still used in modern day devices.

Green energies reached high levels of support in the 1970s when an oil crisis made Western leaders realise how over-reliant their economies were on limited oil supplies. In particular, the recognition that oil in the Middle East could be turned off when diplomacy in the politically volatile region took a turn for the worse led many countries to actively develop options in renewable energies. The result of this was increased funding for what was, despite the many patents already granted, a wave energy industry which was barely in its embryonic stage. Devices of varying technological conception were developed with mixed results.

Optimism was high for the industry and there was genuine expectation that wave energy could become a major contributor to the world energy mix. This can be seen particularly in a report by the UK Department of Industry in 1973, in which it was speculated in the following way:

"Assuming that a wave-power scheme were to occupy 50 per cent of the length of any contour and was then to be capable of converting 50 per cent of the wave energy to usable power gives an overall efficiency of 25 per cent. Using this figure of 25 per cent, half the total British requirement for electricity could be met by the wave energy in a stretch of ocean between 600 and 1400 miles long." (Leishman & Scobie, 1976, p: 5)

An easing of the oil crisis, and the growth of neoliberalism in the 1980s, meant that this period of support for renewable energies gradually subsided. However, the growth of the environmental movement in the 1990s, concerns about greenhouse gases, and the overall realisation that the planet's resources are limited led to the revival of interest in many different renewable technologies into the 21st century.

Basics of Wave Energy

Wave energy is considered to be a form of solar energy. As winds generated by solar forces pass over the surface of the oceans, part of this energy is transferred to the water below. The size of the waves that these forces generate depends on the speed of the wind, the area over which it exerts its force and the length of time which it blows for (Thorpe, 1999, p: 1). It is easy when looking at waves to confuse them for large bodies of moving water. The reality is that waves are the manifestations of the energy generated from the winds as it moves across water. Water is merely the means of carrying this energy as it travels, in some cases, across entire oceans.

Waves have the advantage of being able to travel large distances without losing energy. One of the benefits of this is that, in contrast to wind energy, modelling devices can predict 1 or 2 days in advance what kind of energy will be available at certain locations.

It is estimated that, worldwide, the potential resource which could be harnessed from the waves is over 2 Terawatts (TW). To put this into perspective, the total UK grid capacity is 80 Gigawatts (GW) with a maximum, peak demand of 65 GW (Drew et al., 2009, p: 887). Due to varying climates worldwide it is obvious that the potential for wave energy is greater in some regions than others. For example, due to prevailing winds from the west, the western coasts of Europe and the United States are subject to some of the greatest wave energy in the world. Other areas of high wave intensity are Australia, New Zealand

and South Africa. These prevailing winds tend to blow strongest in the winter, thus creating larger waves and greater energy. This is an extra advantage for wave energy as electricity demand tends to be highest in the winter.

General Overview of Technologies

In general, despite the hundreds of patents which have been taken out, particularly since the 1970s, no single company in the world has reached the point of successfully harnessing wave energy on a commercial level. There have been some examples of test sites where devices have been tested and produced small amounts of electricity[3] but this is as far as any developer, worldwide has come.

Companies developing wave energy convertors (WEC) are mostly small or medium sized enterprises (SMEs) with a single patent. These companies vary in technological development, from concept stage to full-scale testing. WEC's can be separated into a few basic conceptual frameworks.

Oscillating Water Column

As a basic concept, the Oscillating Water Column (OWC) consists of a chamber which is partly submerged in the water. As the wave comes into contact with the device, it forces the air within the column to be compressed upwards. This, in turn, causes a turbine to spin, converting the energy into electricity (Falcao, 2009, p: 904). As the water recedes from the column, the air is then released, causing a vacuum. This also causes the turbine to spin. The nature of modern turbines is such that, regardless of the direction of the air flow, the

[3] http://www.emec.org.uk/about-us/emec-history/

turbine will spin in the same direction. This means that these devices will extract energy from each wave twice.

Point Absorbers

Point absorbers usually consist of a large buoy which is in two separate parts, one which is stationary and one, within it, which is not. As the wave comes into contact with the buoy, it causes the non-stationary part to move in a heaving motion. As this part moves against the stationary part, hydraulic components are put into motion and these are used to convert the energy into electricity (Falcao, 2009, p: 907). Because of their small size, and usually circular dimensions, these devices have the advantage of being able to absorb energy regardless of the direction of the waves.

Surging Devices

These are usually horizontal devices which face in the direction of the waves. Surging devices generally consist of several parts which are strung out in a line, most often in the shape of a large snake. As the power of the wave comes into contact with the device, the parts, which are connected by joints, move against each other. The force of these moving parts is resisted by hydraulic rams which pump high pressure oil through hydraulic motors via smoothing accumulators (Clement, et al., 2002, p: 424). This kind of device is best exemplified by *Pelamis*, a Scottish company which has been seen in recent years to be one of the worldwide leaders in wave energy conversion.

Overtopping Devices

Overtopping devices are similar to hydro-electric dams in their configuration. Resembling a large basin, the wave is focussed towards a ramp and then fills a high-level reservoir. The gathered water is then forced downwards and the energy is converted through a turbine (Clement, et al., 2002, p: 425). These are the least common of all devices currently in operation.

Onshore, Near-shore or Offshore

WECs can either be deployed onshore, near-shore or off-shore. Onshore devices are fixed to the shoreline and this has the advantage of easier installation and maintenance costs. Having devices onshore also means that there is no need for elaborate mooring devices or underwater cables to link the devices to electricity grids. On the other hand, the power of waves is diminished as it reaches the shoreline, due to interaction with the seabed. This means that these devices are making use of a much lower supply of energy. In addition, having devices onshore opens them up to environmental concerns like shoreline geology and coastal scenery (Thorpe, 1999, p: 2).

Near-shore devices are the most uncommon of the three. This is probably because they neither make use of higher wave energy which could be obtained further out or have the convenience coming from onshore devices (Drew, et al., p: 888). Environmental concerns are almost the same here as they are for onshore devices.

Offshore devices seem to be, by far, the most common. As mentioned above, the further from shore a WEC is situated, the greater velocity and energy it is exposed to (Drew et al., 2009, p: 888). In general, this means that most offshore devices are seen to be at their optimum position between 5 and 10 kilometres from the shoreline and at a depth greater than 40 metres.

The main challenge facing off-shore devices is reliability. As WECs in the open seas will inevitably be faced with the worst of ocean storms, it is crucial that they have the ability to survive. Because it is more expensive to develop WEC devices if they are designed to be more robust and to withstand harsher sea conditions, a negotiation between operational safety and economic competitiveness needs to take place:

"Therefore, the design of a wave energy convertor requires a high degree of sophistication to provide sufficient operational safety in extreme conditions on the one hand, but also be economically competitive on the other." (Clement, et al., 2002, p: 417)

In addition to this, accessibility is a big factor for offshore WECs. Aside from the inevitability of maintenance and repair of devices which will break down at some point in their lifetime, regular servicing will also be required. Because the nature of the devices is to extract energy from harsh sea conditions, it is these very seas which will have to be negotiated for servicing and maintenance. This will require expensive vessels, long journeys and skilled seamen.

Wave Energy in Ireland

The Irish Economy

In order to obtain a holistic overview of the wave energy sector in Ireland, a background on the Irish economy is vital.

The Republic of Ireland, with a population of around 4.5 million, is a country of few natural resources, with most of its indigenous industry coming, historically, from agriculture. In recent decades, a lowering of the corporate tax rate to 12.5%, coupled with an increasingly globalized world economy, has attracted huge multinational companies like

Dell, Intel and Microsoft to Ireland, thus creating a buoyant manufacturing and export economy.

> "By the end of the 1990's, Ireland had become the second largest exporter of packaged computer software in the world after the United States. Twelve of *Fortune's* top twenty electronic companies and all of its top ten pharmaceutical companies had plants in Ireland." (Donovan & Murphy, 2013, p: 17)

Ireland underwent a period of huge economic growth in the late 1990s and early 2000s, its economy characterised by the nickname, 'The Celtic Tiger.' By 2007, economic growth averaged over 5 per cent, unemployment was only 4.5 per cent and government debt to GDP ratio hit an all-time low of 25 per cent (Donovan & Murphy, 2013, p: 1).

During this period, a combination of light regulation of the banking sector and cheap credit resulted in a massive property boom in Ireland. Banks became caught in a cycle of competitive lending which ultimately resulted in them being exposed to billions of euros worth of debt to property developers. The folly of this became obvious when the overvalued Irish property market collapsed in 2007, leading to a banking crisis which was compounded by the collapse of Lehman Brothers in September 2008. Fearing a run on the banks, the Irish government guaranteed all deposits in Irish banks, effectively tying the Irish taxpayer to bank debts which it soon emerged amounted to €120 billion, three-quarters of Irish GDP (Donovan & Murphy, 2013, p:8). To compound matters, the over-reliance of the Irish economy on the property sector meant that its collapse led to a separate fiscal crisis as tax intake decreased and growing unemployment led to an increase in welfare expenditure.

The Irish economy was in free-fall and this culminated in the bailout of the Irish state by a troika consisting of the European Union, the European Central Bank and the International Monetary Fund (IMF). No longer being able to dictate its own economic policies, the Irish state has since undergone a period of German inspired 'austerity' economics. This has resulted in increased taxes for the everyday consumer and small business, decreased government spending and an overall contraction of the Irish economy. To this day, the Irish economy is feeling the effects of this momentous shift. Emigration is widespread, unemployment is fluctuating between 13 and 15 per cent and credit from banks is extremely difficult to come by.

The Wave Energy Sector

Ireland is a small island on the north-west of Europe. With a long western coastline exposed to the Atlantic Ocean, Ireland is seen by many to possess one of the greatest resources of wave energy in the world[4]. This is a position not lost on the authorities in the country and various mechanisms are in place to realise this potential. Despite this, wave energy has not yet reached the point of commercial production in Ireland, or even that of full-scale testing. In order to gain a deeper understanding of the position of wave energy in Ireland an identification of the most important actors involved is crucial.

The European Commission

A key driver for the growth of renewable energies in Ireland is the European Commission (EC). In 1997, the EC proposed that the EU should aim for a 12% share of renewable energies across the EU by 2010. Take-up of this, with some exceptions across the region, was relatively slow and the target was not met. As a result, the EC proposed a more rigorous and binding legal framework of a 20% share of renewable energies across the EU by 2020[5]. This is an overall number for the entire region and different countries have different targets

[4] http://www.maps.marine.ie/wave/default.aspx
[5] http://ec.europa.eu/energy/renewables/index_en.htm

in order to contribute towards this. In Ireland, this requires a 16% share of gross final energy consumption from renewables by 2020. The EU directive was formally adopted in April 2009 (O'Hagan & Lewis, 2011, p: 773).

Needless to say, motivation for legislation like this stems from the general world view, and growing acceptance, that the proliferation of greenhouse gases is having damaging effects on the earth's atmosphere. This took on real substance with the Kyoto Protocol of 1997 and has been a huge driver in the growth of renewable energies since.

Unlike in the United States where the right-wing, almost en-bloc, continues to oppose any legislation for Climate Change, referring to it as a 'hoax', the European Union has been able to push through legislation in a relatively smooth way. As the power of the EU grows even greater and countries continue to pool their sovereignty, legislation at this level leaves the Irish government with very little flexibility in drafting its own direction. This is obviously positive for renewable energies in Ireland and can be seen as a direct factor in the funding and growth of wave energy technologies in Ireland.

The Irish Government

In 2007, off the back of a decade of rapid growth in Ireland, the ruling Fianna Fail party enjoyed one of the biggest electoral successes ever in Irish politics. Irish governments are almost always made up of coalitions and this time was no different with the incumbent party failing to reach an overall majority by themselves. Despite this, Fianna Fail obtained 81 seats, accounting for 41.5 per cent of the overall share of the vote. The 6 seats obtained by the Green Party were enough to prop Fianna Fail up in forming a government[6]. Following the formation of this coalition, the Green Party's John Gormley was made Minister for the

[6] http://en.wikipedia.org/wiki/Irish_general_election,_2007#Result

Environment and Eamon Ryan Minister for Communications, Energy and Natural Resources. Soon after the election victory, a White Paper on energy was produced by the new government. This contained a huge boost to the wave energy industry. An Ocean Energy Development Unit (OEDU) was established within the Sustainable Energy Authority of Ireland (SEAI) and this was given the authority over an Ocean Energy Development Fund of €26 million which was targeted to be delivered over 3 years. Specific provisions within this fund included:

- €1 million towards a new ocean energy facility in University College Cork (UCC), including a new wave basin for testing of small-scale devices
- €2 million toward the construction of a new full-scale test site off the coast of Belmullet, County Mayo
- €2 million in grants towards prototype testing
- The establishment of the Ocean Energy Development Unit (OEDU) within the SEAI which gained full control over policy and funding for wave energy
- A feed-in tariff of €220 per MW/hour for wave energy devices[7]

Within the Irish government, the Department of Communications, Energy and Natural Resources (DCENR) has direct jurisdiction over all renewable energies and, thus, the wave energy industry. Following the EU deal for renewable energy targets in the EU for 2020, and in reaction to the various papers produced by the SEAI, the Marine Institute (MI) and the Hydraulics and Maritime Research Centre (HMRC), the DCENR published a draft National Renewable Energy Action Plan in June 2010. This document, like the 2007 White Paper,

[7] *1st Annual Report on the Implementation of the Programme for Government, 2007-2001,* (2007) p: 14

estimates that 75 MW of energy will come from wave and tidal energy by 2020.[8] To put this into perspective, total energy consumption in Ireland in 2004 was 25.6 Terawatt hours (about 60 per cent coming from imported oil and natural gas) so even if this target is met it will have very little impact on the Irish energy map.[9]

Following the economic collapse, the Fianna Fail-Green coalition was swept from power in the 2011 general election. The Greens lost all of their parliamentary seats and a new coalition was formed by the centre-right Fine Gael party and Labour from the centre-left. Labour's Pat Rabitte now occupies the position of Minister for Communications, Energy and Natural Resources. Although there are no signs of a change in policy towards renewable energies, it would appear that wave energy has lost a significant driving force with the demise of the Greens.

The Sustainable Energy Authority of Ireland (SEAI)

The SEAI was established as the main authority on energy in Ireland following the Sustainable Energy Act of 2002. It is partly funded by Ireland's EU Structural Funds Programme which is co-funded by the Irish government and the European Union. According to their website, the SEAI aims to advise government while "transforming Ireland into a society based on sustainable energy structures, technologies and practices…SEAI's actions will help advance Ireland to the vanguard of the global green technology movement, so that Ireland is recognised as a pioneer in the move to decarbonised energy systems."[10] Implicit in this is the support of SEAI in innovation products based on renewable energy technologies.

[8] http://www.dcenr.gov.ie/NR/rdonlyres/C71495BB-DB3C-4FE9-A725-0C094FE19BCA/0/2010NREAP.pdf
[9] http://ec.europa.eu/energy/energy_policy/doc/factsheets/mix/mix_ie_en.pdf
[10] http://www.seai.ie/About_Us/

In terms of shaping wave energy policy and strategy in Ireland, SEAI is a key actor. In 2002, SEAI and the MI produced a White Paper detailing the potential for wave energy in Ireland. Following much consultation with a variety of actors, the SEAI and MI produced an Ocean Energy Strategy document in 2005, which was released by the Department of Communications, Marine and Natural Resources.[11] This paper proposed four distinct phases in the development of wave energy technology, with an ideal timeline:

- research and development (2005-2007)
- pre-commercial demonstration (2008-2010)
- large-scale, grid connected arrays (2011-2015)
- large scale market deployment (2016 onwards)[12]

Crucially, the SEAI is the department which issues funds to wave energy developers and researchers through the Ocean Energy Development Fund, which was established in 2008. This is appropriated either directly to industry or to research organizations like the HMRC. On their website is a document detailing all of their funding up to 2012.[13] This includes many different things relevant to the wave energy industry like testing of turbines for individual devices, tank testing, specific testing for certain companies and many others. Importantly, the SEAI decides whether certain companies qualify for funding and a recent document shows what requirements need to be satisfied if funding is to be obtained:

"the actual funding level provided will depend on the detailed evaluation of the project with regard to: administrative and technical compliance; acceleration of the development of ocean energy in Ireland; ability to overcome technical and other barriers; contribution to

[11] SEAI and MI, *Ocean Energy in Ireland* (2005)
[12] As above, p: 2
[13] http://www.seai.ie/About_Us/SEAI-and-EU-ERDF-Funding/ERDF.pdf

the development of an indigenous OE industry; environmental compatibility; project management capability."[14]

Also important is the leading role that the SEAI plays in the establishment of test sites for devices. This began with a 1:4 scale site in Galway Bay and plans are in motion to establish a full-scale facility at Belmullet, County Mayo known as the Atlantic Marine Energy Test Site (AMETS). This full-scale site is planned to be grid connected, a fundamental requirement for wave energy devices and will be available for use free of charge.

The Hydraulics and Maritime Research Centre (HMRC)

The HMRC in University College Cork was established in 1979. It operates the only wave energy test tank facilities in Ireland (Dalton, et al., 2010, p: 2341) in the shape of the Wave Flume and an Ocean Wave Basin.[15]In addition, the HMRC provides independent and design support to independent developers. Support covers things like physical model testing, concept design, computer modelling, device performance validation, resource assessments and offshore data monitoring.

Because the ocean energy sector is seen to be in its 'embryonic' stage of development, R&D and general support are very important, thus making the HMRC a crucial actor. The Ocean Energy Strategy document produced in 2005 by the SEAI and the MI highlight this:

"It is proposed to implement an ocean energy strategy to advance the speed at which ocean energy technologies are deployed in Ireland by increasing the capacity for research and development, both within academic institutions and commercial entities developing devices in Ireland."[16]

[14] SEAI, *Programme Application Guide,* (2013) p: 5
[15] http://www.ucc.ie/en/hmrc/
[16] SEAI & MI, *Ocean Energy in Ireland,* (2007) p: 2

Furthermore, in 2003, the HMRC produced a Development and Evaluation Protocol for WECs.[17] This is an extensive document recommending the procedure for the development of WECs in Ireland. This document recommends 5 stages for developers of devices to follow in order to reach full commercial production. It is based on a realistic assessment of the wave energy sector with the aim to speed up technological development instead of providing another bureaucratic hurdle:

"This documented structured approach should reduce, if not eliminate these hold-ups, while at the same time providing the designers with a valuable information tool to progress the device development. The protocol should not, therefore be seen as yet another bureaucratic hurdle that must be cleared but a method of fast-tracking funding options if the device performance warrants progress to the next phase."[18]

Because of the central position that the HMRC holds in the wave energy industry in Ireland, this protocol is vitally important. Indeed, as further investigation will show, public funding for device developers is contingent upon developers following this protocol. This makes it a crucial actor in the overall wave energy system in Ireland.

Ocean Energy Ltd.

In Ireland, the leading developer of WECs is Ocean Energy, Ltd., a company located in Cobh, County Cork. Since its inception in 2003, Ocean Energy has developed a WEC based on the Oscillating Water Column (OWC) concept. Unlike some other OWC devices, this device, known as the OE Buoy, is floating and is planned, at full scale, to be located offshore.

Central to the importance of this design is its overall simplicity. At a basic level, the OE Buoy is a giant raft with a partially submerged water column feeding up to a turbine which converts the power of the waves into electricity. Overall, it is this simplicity which

[17] Ocean Energy: *Development and Evaluation Protocol* (2003)
[18] As above, p: 3

contributes towards the ultimate robustness and survivability of the device, as the Ocean Energy website confirms:

"To work in such a hostile environment the platform must be designed to extract energy from the waves efficiently and also survive the worst of ocean storms."[19]

The most important component on the OE Buoy is the turbine which will work twice per wave- as the water comes in and pushes the compressed air through and as the water recedes, creating a vacuum. This is thanks to the technology invented by Dr Allan Wells in Queen's University, Belfast in the mid-1970s. The turbine is self-rectifying which means that its torque is not sensitive to the direction of the air flow (Falcao, 2009, p: 912). The functioning of this turbine is crucial to the overall success of the Ocean Energy device. Indeed, power equipment like this, whether it is a turbine, mechanically or hydraulically based, is "possibly the single most important element in wave energy technology, and underlines many (possibly most) of the failures to date (Falcao, 2009, p: 911)."

Because the OE device is situated off-shore, it is obviously impossible to attach it to the sea bed. Therefore, it needs to be safely held in place by a mooring device. This accounts for a large part of the overall cost of the device. The strength or weakness of this mooring is crucial to the overall survivability of the WEC.

Testing of the OE Buoy began with a 1:50 scale device at the HMRC in 2003 where the wave basin produced a scaled simulation of open seas. Following this, a 1:15 scale model was produced and tested in the large wave basin at Ecole Central de Nantes, France in 2004 where HMRC staff were used for the testing. Both of these testing phases were deemed to be a success with modifications to the model being made along the way. This led

[19] http://www.oceanenergy.ie/oe-technology/platform.html

to the launching of the 1:4 scale, 28 tonne model in 2006. Testing on this was first carried out in the calmer waters of Cork Harbour before being released into the rougher waters of Galway Bay on the west coast. According to the Ocean Energy website, this was a success: "This open sea test programme has confirmed the ability of the device to behave and operate stably, safely and reliably in real state sea conditions."[20]Following this period of quarter scale testing, the EU FP7 CORES program, in collaboration with the HMRC, engaged in a series of testing for devices used by WECs. The quarter scale OE Buoy was used as the main prototype in testing these peripheral devices.

Wavebob

Before April, 2013, Wavebob provided an alternative to Ocean Energy for indigenous Irish companies creating WECs. Founded in 1999, Wavebob commenced 1:50 scale testing in the HMRC tank facility in UCC in 2002. This was followed up with 1:20 scale tank tests in Hanover in 2003. Most recently 1:4 scale tests have been carried out in inner bay conditions, just off the Aran Islands, off Ireland's west coast[21]. During this time, Wavebob received funding and embarked on joint ventures with a number of organizations. In 2007, it signed a technical services agreement with US car manufacturer Chevron. In 2008, it signed an R&D agreement and joint venture with the Swedish power company Vattenfall in which the company Tonn Energy Ltd was founded and plans were made to develop commercial wave farms off the west coast of Ireland. In 2009, Wavebob signed a teaming agreement with the American power company Lockheed Martin[22]. The rest of Wavebob's funding has

[20] As above
[21] http://www.wavebob.com/key-milestones/
[22] As above

come from public bodies such as ESB, the Irish publicly owned electricity company, the SEAI, the EU and the US Department of Energy.

The technology behind Wavebob consisted of the Bipartite Oscillating Point Absorber concept. This consists of two floating bodies, an outer and inner, which act against each other when the power of the wave forces the inner body to oscillate. The outer structure, called the Torus, is shaped like a doughnut and is also connected to the power take off feature of the mechanism[23]. A large float located in the centre of this has a weight suspended from it which is filled with a buoyant mass of water and remains below the surface of the water. As the power of the ocean swell affects the mechanism, this weight will move up and down, acting against the Torus and creating electricity through a high-pressure oil system (Falcao, 2009, p: 907). The way this device responds to the varying swells of the ocean is one of its biggest advantages over other devices. This allows good overall control as well as an efficient and consistent supply of energy. However, it has been noted that if seas become too rough, the inner buoy can empty of water and the device becomes nothing more than an extremely expensive buoy.[24]The entire device is held in a steady position using loose mooring lines which are connected to the sea bed. The device is typically located 5km from the shoreline where waters are around 100 metres deep and waves provide the optimal amounts of power.

According to the Wavebob website, there are many key advantages to this design. Fundamental to this, like all WECs is survivability. It is claimed that Wavebob can ride large waves and is in tune to the average ocean swell of the Atlantic. In addition, an on board autonomous control system allows Wavebob to de-tune when necessary (e.g. in times of

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[23] http://irishenergynews.com/home/index.php/2010/11/12/ocean-energy-the-topic-of-the-day/
[24] http://irishenergynews.com/home/index.php/2010/11/12/ocean-energy-the-topic-of-the-day/

abnormally high energy sea conditions). In line with this, it is claimed that the device has extremely low operating and maintenance costs which bring down the overall unit costs of electricity produced by the mechanism. Overall, this design has proven itself to be attractive for investors and technicians. In 2010, the publication *Irish Energy News* stated, “As with all new technologies there is a certain amount of excitement but in this case I think it is well deserved.”[25]

Despite all this, in April 2013, Wavebob held a shareholders’ and creditors’ meeting where they informed all in attendance that the company was being placed in liquidation.[26]According to reports, the company had run out of money and had failed to attract any further investment. Crucially, the SEAI refused to sanction any more funds for the company, which was hoping to bridge itself over before attracting €10 million more in investment[27]. As an ominous warning for the wave energy sector, company CEO Padraig Berry stated, “Some of the big players in ocean energy are in fact withdrawing from the sector entirely. Finding a strategic partner and a long-term investor has been impossible and we were almost there a couple of times but they haven’t materialised.”

Preventative Forces

Unlike windmills, the main renewable energy technology in Ireland, wave energy is not faced with any obvious social objections. Part of this is obviously because they have not yet been deployed at full scale and in arrays of multiple devices. However, it is interesting to see that no real opposition has manifested against these technologies when windmills cause such upheaval. The most likely group to be involved in opposition would probably be

[25] As above
[26] http://www.irishtimes.com/business/ocean-energy-developer-wavebob-set-to-go-under-1.1347036
[27] http://www.bloomberg.com/news/2013-04-03/wavebob-shuts-down-after-failing-to-raise-funds-find-partner.html

'Coastal Concern Alliance',[28] an organisation actively engaged in the protection of the Irish foreshore. However, this website contains no explicit objections to wave energy. This organisation was involved in the scoping of a Strategic Environmental Assessment (SEA)[29] for offshore development, a document which includes wave energy, so it is definitely aware of the potential implications of these devices. This leads to the conclusion that social problems are going to be minimal for full-scale wave farms and that developers can concern themselves, at the moment anyway, on other problems like survivability and financing.

Moving Forward

As has been just shown, there are many factors at play which could potentially affect the future course of wave energy in Ireland. While politicians, national institutions and private developers are all acting to realise this potentially great Irish resource, economic turmoil, political change and technological configurations are also having their say. The use of ANT in analysing these factors will help in answering the overall empirical research question of this thesis. An understanding of the ways in which the different forces are interacting with each other and, particularly, in what the various actors are saying will provide a fresh tool in helping to move the sector forward.

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[28] http://coastalconcern.ie/index.html

[29] *Strategic Environmental Assessment of the Offshore Renewable Energy Development Plan in the Republic of Ireland*, (2010)

Interview Analysis: Following the Actors

Between June and August, 2013, a series of interviews took place of key actors within the ocean energy sector in Ireland. The identification of these actors was based on a number of reasons and it was hoped that their different positions would paint a wide and comprehensive picture of the sector. The actors interviewed were:

- **John McCarthy**, CEO of Ocean Energy Ltd. With experience in development projects, particularly in the wind energy sector, John co-founded Ocean Energy in 2003. Since then, he has helped to develop the company's Wave Energy Convertor (WEC), the OE Buoy.
- **Brian Holmes**, Coastal Resources Manager at the Hydraulics and Maritime Research Centre (HMRC). Brian has been closely involved with the scaled development of a number of WECs in Ireland, including the OE Buoy and Wavebob. He also wrote the 5-stage protocol for the development of WEC devices, something closely adhered to by most developers, including Ocean Energy.
- **Jochem Weber and Ronan Costello**, both members of the Centre for Ocean Energy Research at National University Ireland, Maynooth, Jochem as a researcher and Ronan as Deputy Director. Both were involved in the technological development of Wavebob.
- **Eamon Ryan,** current leader of the Green Party and Minister for Communications, Energy and Natural Resources in a coalition government between 2007 and 2011. During this time, he had direct political jurisdiction over the wave energy sector.

Apart from these actors, several attempts were made to set up an interview with the Sustainable Energy Authority of Ireland (SEAI), the body directly responsible for public funding of wave energy developers and the mouthpiece of the government when it comes to all matters related to renewable energies. These attempts were continually met with a lack of response and, due to time constraints, it was eventually accepted that an interview with this actor would not be possible.

Throughout the course of these interviews, a number of themes persistently arose related to wave energy in Ireland. These were:

- Economics and Finance
- Protocol
- Technological Development
- Politics

As analysis of the interviews will show, these are all themes that are intrinsically related. For example, it is impossible to discuss the financing and investment of WECs without seeing how that that is linked to protocol and technological development. Similarly, the political situation is closely related to economics and public financing, things which will eventually have their own effects on the paths chosen by developers. This interconnectedness is exactly what proponents on ANT and co-production have tried to demonstrate in various other empirical cases. As mentioned in previous chapters, according to these theoretical frameworks, it is impossible to separate these elements into neatly separated sections as they are constantly interacting and continually shaping one another.

Nonetheless, some kind of separation needs to be made on paper in order to make sense of these themes. Therefore, they will all be addressed in separate sections with attempts made, throughout, to show their linkages.

Economics and Finance

From a starting point, it is accepted that funding is possibly the most important variable when it comes to the development of WECs. It is estimated that from initial concept to full-scale development it costs anything from €15-20 million to develop a device. The cost, thereafter, per device is estimated to be anywhere between €2-4 million. Because the wave energy industry is still barely in its embryonic stage, most developers involved are small and medium sized enterprises (SMEs) with very little in the way of initial funding. This makes them extremely dependant on funding from both the public sector and private investors. In light of this, the wider economic climate is crucial. A buoyant economy means higher employment, increased domestic spending, higher tax intake and more funds available to the government for public spending. In positive economies, investors have more money to invest which provides the framework for taking more risks. This is a point widely agreed upon by all actors interviewed, especially in light of the collapse of the Irish economy between 2008 and 2009, a situation which continues to this day.

> **John McCarthy**: "…the difficulty I suppose for most companies in the past 4 or 5 years is that the global financial crisis in that the credit crunch that was a shortage of funds to go into this type of R&D investment because investors are in the market place…they've much better opportunities in terms of what's available so they could be more selective in terms of their choosing…and the same issue has seeped into government funding in that governments, you know, 6 or 7 years ago they had unlimited pots of money to put into this type of technology or into new R&D but that situation has completely changed, so now they're trying to be much more focussed in terms of what they're putting the money into and much slower in terms of making decisions…"

> **Brian Holmes**: "No, the biggest Irish problem is that we have no money… As I said…SEAI got directly behind the 5 stage development…they were always going to have calls for the different stages…they were going to put money available…the same as the Americans did…are doing…they were going to make it and gradually…so

> fund a few at smaller scales and work them through so that you'd separate out what the best ones were…and finish up with 2 or 3….but we just ran out of money…"

> **Eamon Ryan:** "…and I think the financial crisis in Europe has created a general lack of confidence in the whole European Union project…in our work on climate and energy as well as everywhere else…"

> **Jochem Weber:** "…maybe it would have increased in a better financial environment but the private investments have suffered from the financial crisis certainly and that has made it very difficult for small companies to secure funding…"

As mentioned, the nature of the funding is either public or private. These are both dependent upon each other, each expecting an input from the other side as a provision for their own investment:

> **JM:** "They're actually both critical…developments won't happen without public funding and public funding won't give you a hundred per cent of the cash required so you're going to…you require a mix of both…in any of the, we'll say the grand schemes or funding schemes available, you know the max that you will get is somewhere between 45 and 50 per cent from government or EU or the RDF, whatever it happens to be so the difference has to be private funds because the, I suppose the EU or whoever, the public bodies want to see commitment from the private sector and at the same time the private sector want to see a commitment from the public sector to make this thing a viable sector…"

The attraction of private investment is something that should always be in the background with the development of these devices. This is a point accepted by most actors involved in development and is even an inherent part of the protocol developed by Brian Holmes and the HMRC. When discussing one of the reasons for developing devices at quarter scale, he concedes that this is the kind of size that investors can see and be attracted to:

> **BH:** "…that's why…it's becoming a big lump so it's the sort of thing now that investors can see…and it's in the ocean and it's producing power…that's what that meant…that you're getting to a time now that you can start taking investors around it…you stick them in a boat and you sail out and you go around…on a calm day…you go around and you can see it…you can get aboard it maybe…that's what that means…"

> *So, that's a kind of offshoot…the positive result of quarter scale is that investors can see it…*
>
> **BH:** "Yea, if it's the size of this table…investors, VPs, these sort of investors…bankers…you know they don't want…it wouldn't lob with them properly…whereas something out in the ocean that…and then you just have to explain to them that this is 2 million rather than 20 million…that's why you're doing it…but they start to believe the (inaudible) they're in…if you've got something this big and you go to a banker and you say, it produces this amount of power and they say, well, does it really…you know, he doesn't know what route scaling is…the laws of similitude…whereas if you have quarter scale and you actually have lights lighting, whatever, you know that's what that's supposed to mean…"

As stated by Brian Holmes, one of the motivations for developing a device at a certain scale stems from what the perception of investors and investors' motivations are. This scaled device will then encourage investors to put their money into the company and this will hopefully result in the eventual emergence of a full-scale, commercial device.

Protocol

"People who study technological projects take too little interest in the official doctrines dealing with the actual management of the projects. This metalanguage appears parasitical. Yet it plays the same essential role that strategic doctrines play in the conduct of wars…ideas about the way to handle battles or innovations play a performative role."

(Latour, (1996) p: 112)

As stated above, private and public funding are equally important when it comes to the emergence of WECs in Ireland. Both sectors require a commitment from the other when it comes to investment in development programmes. However, the different nature of each sector means that funding is attracted through different mechanisms. While the private sector is relatively free, and companies can use their own tactics in attracting investment from whoever they want, the public sector is a lot more rigid.

Callon describes *Obligatory Passage Points* when describing how networks are formed and how certain actors make themselves interesting to other actors (Callon, 2007, p: 61). The way in which this is done means that those actors placing themselves in these positions of influence and importance make themselves indispensable to other actors wishing to succeed in the same network. In a way, this is what has been done with the HMRC and their 5-stage protocol. Any company in Ireland wishing to develop a device will most likely have funding needs and in order to access the public pot it will first go to the SEAI. It is also likely that the developer will require some development expertise to go from his or her concept stage to something resembling a real device. Because the SEAI believes into the HMRC's protocol, and will not release funds unless a developer goes through this established route, developers have no choice but to follow the path set out through the protocol. This makes the protocol a key actor and, together with the HMRC, an *Obligatory Passage Point.* The way in which this was achieved was relatively straightforward:

> **BH:** "…we expanded it considerably and the SEAI…the reason we wrote it, we expanded it for Ireland was that quite often there'd be people coming along looking for funding for projects…you know, 10, 15 million to go out and stick something in the ocean, and…the public funding bodies turned around to us and said how do we know whether to invest in this, you know what can we apply, what rules, how do we evaluate the proposals? So we said, look, why don't we write this…expand this 5 stage development…"
>
> "…the way it works and the way it worked in Ireland before we ran out of money was SEAI, [name omitted], was a big believer in it and people were going to him saying, I want to build a full-scale unit so give me 20 million, and he said, well I'll give you 2 million and you can build a quarter scale unit…"
>
> "…for that really to fully completely work the funding agents would have to be behind it and that's the advantage we had in Ireland for a few years…SEAI, the main funding agents were behind it so people would go to SEAI and say I want to do this and they'd just say, ok, show me the previous…show me the results…we'll evaluate your proposal on your previous results and if there weren't any then they'd say, no you have to go back…"

The HMRC's 5-stage protocol is written with the best interests of the wave energy sector in mind. It is based on the 'Technology Readiness Level' concept, which was developed by the United States military and space agencies, and which is based on beginning with a small scaled model (TRL 1 or HMRC stage 1) and gradually moving up to full-scale commercial readiness (TRL 9 or HMRC stage 5). The text of the 5-stage protocol contains a recognition of every aspect of the realities facing developers, particularly those relating to financing and investment, and is explicit in the importance of wider social factors when developing WECs.

> **BH:** "It's based on things like NASA followed on…and as I was saying earlier, any good engineering company wanting to develop a product…if you can use scaling and if you're developing an ejector seat you build it in bits before you bring it together but you wouldn't actually build a small scale ejector seat…so not everything can follow that rule…but it still follows that basic principle that you don't just build the whole thing in one go, you…the whole idea is to mitigate technical and financial risks because obviously with a wave energy device…any ocean energy device but a wave energy device in particular…you start off with some fairly complex physics, hydrodynamics…and you finish up with huge, heavy offshore engineering and that's the span they have to do so to develop a wave energy device is inevitably going to be a long process and a reasonably expensive process involving lots of different elements as you go along the path so the idea of this staged development is to just look at the right thing at the right time…and the advantage we have in this sort of work is this route scaling, this similitude laws that if you follow them you should always…you should be able to…it's not just boys playing with toys…you are doing, even on a small scale, you are doing good, sound science…"

In general, this protocol has been followed, particularly by Wavebob and Ocean Energy, the two companies at the forefront of development, before the demise of Wavebob in April, 2013.[30]For Ocean Energy, the protocol was valued very highly:

> **JM:** "…so there are a whole lot of reasons why testing the tank and that's why the HMRC, this development protocol…and that is something that we have followed very closely over the past 10 or 11 years…we started off with a very small scale device

[30] Before the closure of Wavebob it was stated on its website that the HMRC's protocol was followed closely during its technological development. Because this website is no longer available, it is not possible to provide evidence of Wavebob's adherence to the protocol.

because…a 1:50 scale device was basically, you know, a metre long by half a metre wide…and then we went to a 1:15 scale device which was maybe you know 3 metres long and a metre and a half wide…then we went to the quarter scale which we had in Galway Bay for 3 years, that was 12 metres long by 6 metres wide, weighed about 28 tonnes so the next step for us is to go to the commercial prototype…so that basically, that's a slow process in terms of the evolution of the technology…"

…you talked about…you said you followed the HMRC's protocol…pretty much exactly was it?

JM: "It was yea…and we think that has been…well that has been a major advantage to us in terms of getting further funding from the Irish government and other bodies but also in terms of developing the technology itself…"

Nonetheless, the HMRC's protocol is not widely received by every actor in the sector. As mentioned above, Jochem Weber and Ronan Costello were both involved in the technological development of Wavebob and since then they have developed a new protocol which they believe to be more suitable for the development of WEC's. This brings in a new variable, Technological Performance Levels (TPLs), which they believe should be considered from the earliest stage of development as well as the TRL. The goal of this is to consider economic metrics like Cost of Energy (CoE), Capital Expenditure (CapEx) and Operational Expenditure (OpEx) more closely when developing devices instead of taking development on a purely technological path. This should be done at an early stage with the emphasis on flexibility of system design, something Weber believes is lacking in the wave energy sector:

"Thus, within the research dominated domain of low TRLs, advantageous alterations to conceptual and technological system fundamentals are not only practical but should also be encouraged in order to achieve the desired high TPL." (Weber, 2012, p: 6)

Even though it is explicitly stated in the HMRC's protocol that these factors are considered in development, Weber and Costello's TPL concept aims to go further.

Ronan Costello: "It's a disincentive to strategy if you use these readiness…the readiness scale without the performance scale is a disincentive to strategy…because at each point along the scale, you…you know, a developer only has to ask himself,

> what do I need to do to get to the next point on the scale…but if you have two scales on a plain and you have this readiness and this for performance, it's more of an incentive tor strategy because you have yourself…I have X budget for the next 12 months, can I spend that best in improving readiness or in improving performance and in the early stages it should almost all be spent on improving performance but it's really…it's a kind of false sense of progress because you get…if you race up the readiness scale without looking at the performance and you invest money in that you could really quite quickly get half way or more up that scale without much investment if you don't look at how good whatever it is you're working on…so if your only objective is to have something that's high on that readiness scale there's no strategy involved…you just plough your initial money in, get half way up, run out of money, go bankrupt…whereas, if you have these 2 axes and you have to think about the strategy of how good really is it, how do I spend my initial money, then you're actually in a better position if you do that thinking about strategy and you move up the performance level first, you're in a better position to raise more money and avoid going bankrupt half way up the readiness scale with a product that no one wants to invest in…so it's better, it's more of an incentive to strategy to look at both performance and readiness as separate scales..."

Throughout the interview with Weber and Costello, they were both reluctant to directly refer to Wavebob. Therefore, it is difficult to say definitively whether the TPL concept was developed as a direct result of the demise of Wavebob and its use of the HMRC's protocol, although Weber and Costello do talk about 'mistakes which have been made in the industry' as part of their motivation. What the TPL concept tries to do is integrate the social into the technology from an earlier stage and make that a greater consideration throughout development. This is explicitly stated in the interview as a direct response to the HMRC protocol.

> **JW:** "No, em…the 5-stage protocol is only comparable really to the 9-stage technology readiness levels because it asks…it asks, or it gives you guidance on what you should have done before you engage into a follow-on step…and it's very…one key aspect of it is the scaling and the size of the technologies, the type of laboratories they use, the types of simulations they make…but it doesn't make many statements about the quality that you need to reach…some of them are made, yes, but…when I talk about trajectories I really only start talking about them when I bring in the second dimension because as long as you only have one dimension you can go

> along this path, you can make other mistakes which have been made in the industry that people jump from…and I'm sure Brian said something like that as well…that people go to large-scale testing too early, they're not mature enough for it…because they haven't done…they haven't answered or de-risked the project in cheaper and more effective ways in laboratory or in simulation or in other engineering analyses before…ok, so…the essence of the protocol is not to jump steps but the protocol will not tell you…ok, now at stage-so and so you haven't reached that kind of quality in…you've done everything right, you've done everything that it says in the protocol but it doesn't give you guidance in saying, well, you actually…what comes out of your result isn't good enough, you have to rethink it…"

The TPL concept aims to consider all factors related to devices when considering costs at an early stage. This includes things which are not initially obvious like costs of bringing devices out to sea, operation and maintenance (O&M) and the likelihood of devices breaking down. If a comprehensive consideration can be obtained, then this will make investment more likely down the line.

> **JW:** "Yea…and this how good is it is a very important thing…we don't know how good technologies are, particularly not at early stages….it's very difficult, that's why we need these told that Ronan discussed…and investment industry doesn't have it, the funding industry doesn't have it…many different developments for determining the cost of energy have been done but I believe that a richer set of criteria for assessment needs to be used and hopefully at some stage agreed on in the industry to have a standard or at least recognised…widely recognised guidelines on how technologies then can be assessed and their quality can be quantified and on that basis they can also be compared…and that should then have an impact on investibility of technologies on the development…in, you know, one of the other things I keep repeating is that the TPL's are hoped to support investment on the merits of the technology rather than on the quality of the chief financial officer…"

When it was put to John McCarthy of Ocean Energy that Weber and Costello believe the TPL dimension should be considered in more depth, he was somewhat dismissive, saying that it is obvious that a developer should be looking at these factors from the start.

> **JM:** "Well I would expect…well, to be honest I wouldn't…now, HMRC may be able to assist in the provisional service but I would expect that every commercial company that's developing a technology, that's the first thing they do…you know, you come

> up with your concept, you test the concept, you cost the concept, does it make sense, you know, is it commercially viable, no, well then you stop (laughs)…"

In light of the many failures which have beset the wave energy industry worldwide, including the recent one from one of the beacons of Irish development, it is interesting that these words come from the CEO of a company at the forefront of development, not only in Ireland, but one of the most advanced in the world. What is obvious to the developer of Ocean Energy may not have appeared the same way to Wavebob or other companies. A deeper investigation of the technology path chosen by Ocean Energy would seem to back this up.

Technological Development

As stated within the TPL concept, the ideal scenario to fit into the model would be a device that is initially concept-independent at a low TRL stage. This would allow for major systemic, fundamental changes to be made at an early stage, based on economic projections, before too much money and development has been committed to it. For most WEC developers, this is a problem as it is normal for an SME to approach development with a patented prototype and this restricts the amount of freedom available for change. For Ocean Energy, this was addressed in a different way.

> **JM: "**Originally when we started the process back in probably 2001, 2002, no sorry it was later than that, maybe it was 2003, 2004, we looked at a lot of different types of concepts and our first focus as a company was not to be a technology developer, we wanted to be an actual wave farm developer and we were going to acquire wave energy devices and deploy those at various locations but we went into the market place and discovered that there wasn't a commercial wave energy device available…"

Not having a concept actually served to benefit Ocean Energy as it gave them a degree of freedom not available to other developers. After discovering that it was not possible to set up wave farms because of the lack of available technology, Ocean Energy looked at the technologies in the sector and chose a concept based on what they believed made the best economic and practical sense, as opposed to what was purely technological in suitability.

> **JM:** "The original concept, the floating oscillating water column has been around for probably 30 or 40 years…the most successful example of that to date would have been…there's a plant up in Islay, which was a shore-based oscillating water column which was owned by a company called Wavegen which was subsequently bought by a German company Voight…"
>
> "…so it's basically a hollow L-shaped structure with the water coming in and pushing the air through a column…so basically what we've done is take that concept and made it float so in terms of our technology and what it's done, where it's come from, it had an existing based of knowledge, you know, it was proved at a certain level where a lot of the technologies were coming from, you know, basically from a sheet of paper…you know, coming from an original concept, this is an idea, let's develop this…so I suppose that's one of the main differentiating factors for our particular technology…"

From the outset, Ocean Energy took wider factors in consideration, especially when deciding to take the device offshore.

> **JM:** "Onshore there is a very limited market because it's very expensive to build them out, you need large concrete bases, environmental issues in terms of you have to blast rock, you know, to bed in foundations for these, so…plus, you can't expand them, you can't put in multiple devices whereas if you could take these devices offshore….and people had looked at floating concepts of this device, you know, prior to us and we looked at different concepts ourselves in terms of the floating OWC and we had to do a lot of tweaking because there were stages where we said we did the evaluations, that doesn't work, we have to go back to the drawing board, that doesn't work, you know we had to keep doing that…change this, move that, add something else in terms of engineering to make it work and ultimately we did that but it took a number of years in the HMRC testing to do that…"

Commercial considerations were important from the start and this affected what kind of separate elements were used in building the OE Buoy.

What were the main challenges…without getting too technical…but what were the main things that you had to overcome as you went along?

> **JM:** "Bottom line was power production…you know, because unless you get the power production up beyond a certain threshold it wasn't economic so that was the key issue…I mean, it worked but it didn't make financial sense to pursue it so we said, look, we need to make…how can we make this thing more effective in terms of….and, in terms of the devices themselves, you know, irrespective of what type of device, wave energy devices you're not just looking at…the device or the core device, you're looking at other ways of maximising the power whether it's the power convertor, whether it's the generator or the turbine, you're looking at reducing your mooring costs, you're looking at reducing your cabling costs so it's all of those different elements feed into the…just bringing down the cost per kilowatt which is the commercial driver for all of it…"

Importantly for Ocean Energy, commercial considerations were constantly being considered at the same time as other, sometimes external, factors which would affect the overall, long-term, strategic vision of the company. Simplicity and survivability were always prevalent.

> **JM:** "Simple design…I mean it's very simple technology…as most of them actually are…the big differentiator for ours is that we don't have any moving parts in the water which is a major consideration in terms of O&M (Operation and Maintenance), survivability, you know, so we've a turbine that's operating in the air…if the turbine ever failed it's like a cassette, you just swap it in and swap it out…so it's pretty easy, it's not like other devices that might have to be towed ashore and maintained or whatever else using divers which, you know, is expensive and dangerous…and that's why we kind of stuck with the concept at the outset because of its simplicity and the low cost factors in terms of operation, recovery, deployment and it's very easy to build…you know it's basically flat sheets of steel…compared to other technologies which are a bit more complicated in terms of circular structures and tubes and so on…"

Latour states that innovations have to interest people and things at the same time:

"The problem is, the innovator has to count assemblages of things that often have the same uncertain nature as groups of people…to get Aramis past the paper phase into the prototype phase, you have to get a whole list of things interested in the project: a motor, an ultrasound sensor, assorted software, electric currents…some of these actors and actuators are docile, loyal, disciplined old servants…but other elements have to be recruited, seduced, modified, transformed, developed, brought on board."

(Latour, (1996), p: 56)

At the heart of ANT is the non-distinction between human and non-human actors. While investors, politicians and engineers have to be interested in a project in order for it to succeed, at the same time the many different components of the technology have to fit in neatly to the network. Nothing is pre-ordained about human or non-human actors and they all have to be coerced into the network that is formed in and around a technology. This is clearly evident in the development of the OE Buoy. Human actors, like investors, take their place as early as the concept stage. Even if they are not present at that stage, they are already influencing the path of technological development. Non-humans are then added, based on considerations like survivability, cost, recovery and deployment. The consequences of a failure to do this have already been identified by the developer of the OE Buoy.

> **JM:** "In the world…you know cause you just find…and if you look at, if you research other technologies, what happened to them…you know, eighty per cent of the time it's got nothing to do with the technology itself, it's because the moorings went wrong or they got the deployment wrong or they did something…you know that's what happened to the AWS device in Portugal…nothing to do with the technology but the deployment…they weren't ready to deploy when they did deploy so that's what happens…Ocean Links in Australia, their device failed because they had a mooring failure, not because the device wasn't working so a lot of the time it's these side issues, particularly the moorings, that create the problems with the technology and not the technology itself…"

Following the realisation of a concept and the testing of that through 1:50 and 1:15 scale with the HMRC, Ocean Energy built a 1:4 scale device and began 3 years of testing in the relatively benign sea-site of Galway Bay. HMRC protocol was still being closely followed and changes made along the way as different things were learned about the OE Buoy.

> *Do you feel, though, with your 3 years of quarter scale testing then that these side issues are more under control as you approach full scale?*

JM: “Well, we’ve a better idea in terms of what we’re dealing with, in terms of the environment, what can go wrong, how to fix it, what the best O&M strategy is for the device and how to make best use of where the window is in terms of servicing the device so what the 3 years has given us, it’s given us not alone real sea data, real power data, real environmental data, it’s also given us real information about the O&M for the device and how that should be done and how that is best done and without going in to the water with a large scale device you’re not going to learn that…”

Following this testing, a larger actor came into play, further dictating the evolution of the OE Buoy. The EU funded FP7 Project- *The 7th Framework Programme for Research and Technological Development*- provided €50 billion in funding to co-finance research, technological development and demonstration projects.[31] For wave energy in Europe, this manifested into a project called Components for Ocean Renewables Energy Systems (CORES) which was a program for testing component elements of WECs. This programme was spearheaded in Ireland by the HMRC which recruited the OE Buoy as the main device upon which devices would be tested. In the long run, this resulted in a new turbine, new data recording device and new telemetry system for the OE Buoy[32], its developers smartly taking advantage of the cheap knowledge base presented by the EU project.

JM: “After the quarter scale in Galway Bay…I suppose we were lucky enough that following the first deployment in Galway Bay which was about 2 years, 2 and a half years…we then became part of this EU FP7 Project with HMRC…because we were basically finished with our testing, we had all that done…because from the original 1:50 scale device and 1:15 scale device we had gone through a certain program of testing in terms of this is the wave climate, this is the power output so we wanted to make sure that we had the same matching test points in terms of wave climate to see how they correlated and, you know, they correlated very well, the 3 particular devices…and what the FP7 Project did for us, it allowed us to get back into the water…the HMRC approached us and said, look, can we effectively use your device to test all these other components from other companies and SMEs and universities, different turbines, power generation systems, telemetry…so we said yea, no

[31] http://ec.europa.eu/research/fp7/understanding/fp7inbrief/what-is_en.html
[32] Confirmed through email correspondence with John McCarthy (09/09/13)

> problem, so that's what we did with them so that gave us to put in…we put in new telemetry and sensoring recording system which worked far better than the first system that we had…so it gave us a chance to do something…to improve on what we had originally at a substantially reduced cost…"

Input from the EU was a welcome bonus for Ocean Energy but it was their previous relationship with the HMRC, their adherence to protocol and their already entrenched position within the system which resulted in the OE Buoy being ultimately used for testing, and the changes which resulted from that.

Politics

Like we have just seen, politics can sometimes be a powerful force when it comes to dictating the development path of technological devices. Without the money and testing environment created by the EU, the OE Buoy would be different in configuration to what it is today. On a national level, we can also see how political movements and administrative arrangements have affected the wave energy sector in Ireland.

The 2007 general election gave the Green Party their first ever opportunity to play a part in Ireland's governance and it was important for them to make their mark, to finally put into practice the green politics that they had been preaching for many years. Wave energy provided a willing vehicle for the manifestation of these interests, the previously mentioned boost to the sector of €26 million, showing that the Greens meant business.

> **ER:** "…and I guess as a Green Minister in government, we needed some winds, we needed to be showing to…you know that we were actually delivering, kind of, on certain key objectives…so, it wasn't a particularly difficult decision…"
>
> **JM:** "…Fianna Fail might say that they were already aware of it but I think…well it also gave Fianna Fail, they said, look, these are the Greens and they have to introduce a Green agenda so that they were seen to be doing something real in terms of the economy, in terms of the renewable technologies…"

It would be very easy to say that it was green politics that launched the wave energy sector in Ireland but previous research, particularly of white papers on energy, showed that the mechanisms were very much in place before the Green Party came to power. This actually makes more sense in the larger context. The fact that the sector already had some kind of political and social foothold in Ireland, and that there were already some technologies in place, made it a much easier thing for the Greens to exploit for their own political benefit. In a sense, the politics here was being produced by the technology.

> **ER:** "…it was a fairly rational policy decision based on policy work that had been done already and that was…you were keeping it going…so I think it was a reasonably straightforward policy decision…"
>
> **JM:** "Well, they looked at what the situation was and said how can we make this better rather than saying we need to develop new technology…you know, they didn't start from a blank canvas…there was already pre-existing technology and there was already a recognition within government, whoever the parties happened to be that the green economy had a lot of potential so let's fund it…"

Nonetheless, the enthusiasm shown by the Green Party increased the general level of interest for wave energy in Ireland, providing the sector with a boost of confidence. This would not have been as strong if any other party was taking its place in the coalition.

> *Did you think it would have…do you think there would have been a similar level of support if the Greens weren't in government?*
>
> **ER:** "No, I just don't think…I don't think there's another political party who gets the energy transition, gets the urgent need for it or the opportunity from it…and I think, as I said, I'd have high regard for my predecessor [name omitted], I think he's been one of the better Fianna Fail people in terms of he probably does have an interest in the climate change issue and kind of, I would have been picking up a similar thread in many ways from him but…but I think it crossed a whole range of areas…what we did wouldn't have been done by another administration, no…"

Following the financial collapse of 2008, the government in Ireland became extremely unpopular. While Fianna Fail was blamed for poor regulation of the banking and building sectors, and the catastrophic bank guarantee, the Green Party quickly became known as a party unaware of the realities of the time, pushing through its own agenda while the rest of the country crumbled around it. Matters of the environment took a back seat as financial meltdown became the only thing of relevance to Ireland. This resulted in a gradual easing in support for wave energy.

> **ER:** "I think, ultimately it ended up a lack of confidence in the…in the…just the whole country was, in a sense, in a very unconfident framework…like, I was pretty keen, pushing this project so they didn't have a lack of a minister who wasn't supportive but just towards the very end in terms of the agencies who had to deliver…ESB, SEAI, others…they were doing it and we got very close to, kind of, getting there but in the end…and I think with the change of government there was an opportunity for everyone just to take the foot off the pedal and say, this is too risky, this is too long term…put it off for another 5 years…and that's where we are now."

According to other actors, the change in government was less significant than the financial crisis.

> *…there was a change of government in 2011, you had the Greens in there before …did you feel a sense…obviously the financial crisis was around the same time…in a sense was there a shift in terms of enthusiasm for ocean energy?*
>
> **JM:** "No…"
>
> *No?*
>
> **JM:** "They just couldn't write the cheques…"
>
> *Was that it?*
>
> **JM:** "Basically, yea…"

An obvious manifestation of this has been the almost complete disintegration of the Ocean Energy Development Unit, one of the central components of Ryan's plan in 2008. A unit which previously operated with 4 full-time staff now has one staff member focussing only part of his attentions on wave energy.

> **BH:** "…so, ocean energy is still being organised by SEAI but it's almost now on a part-time basis. I think the OEDU, as such has actually evaporated, or at least for the time being…"

> **JM:** "Well it's still there but I think through natural attrition…they'd 4 or 5 people there…4 people left that in the past 12 months…including [name omitted] who was excellent, he was heading up that unit…you had [name omitted] from Cork, [name omitted] is gone to the UK, he was excellent…you had [name omitted] who is gone or about to go and there is another guy who is in there as well and I think he is gone and you have a guy who was originally involved within SEAI before the Ocean Energy unit was set up, a guy called [name omitted] who is now kind of shared through that and some other renewable, biomass or something like that…so it's gone from kind of 4 or 5 people to half a person…"

Smaller bureaucracy has led to a diminishment of the overall administrative support for the sector, something which directly affects and frustrates developers.

> **JM:** "…you know, the lack of resources within the OEDU I suppose is symptomatic of the overall funding crisis that the government has…but the net effect of that is whoever has risen…the net effect of that is that you put in an application and you're told it will take 6 weeks and it takes, you know, 6 or 7 months and that's not acceptable…because that can and has created issues…"

However, as the developer himself says, part of the reason for this smaller bureaucracy for wave energy is the lack of activity in the wave energy sector which is itself a result of other factors, particularly the economic climate. This is a good example of the way in which politics, administration, economics and technology are affecting each other in a multi-directional way and involved in the process of co-production.

> **JM:** "…it's a double edged sword in terms of the OEDU and the reduction of their resources because on the other side of that coin you also have reduced demand on the OEDU in terms of what developers are doing out there and I don't think they've got as many applications on their desk as they might have had 8 years ago, you know what I mean…or 5 years ago, whenever they came into existence…"

Summary

Overall, these interviews have provided an even deeper perspective on the Irish wave energy sector than that garnered through the literature review. ANT emphasises the need to ‘follow the actors’ if a true picture of any network is to be properly gained. This is because these are the people most involved in the network and it is they who are dictating its path. Further analysis of these findings, from an empirical and theoretical perspective, is required in order to answer previously mentioned research questions.

Discussion

Empirical Findings: An Application of ANT

The use of ANT in answering the research question, *"What needs to be done in order for wave energy to be successfully implemented in Ireland?"* means that ANT needs to be present in the answer.

The literature review and empirical findings from the interviews show that a clear network has been formed in Ireland for this sector. To start from the centre, we can see that there are two developers of WECs in Ireland. One is full of confidence, ready to advance and the other no longer exists, its demise being blamed on the lack of a financial transfusion from the SEAI which would have kept it alive. Existing in tandem with these two companies is the HMRC which aids them in the realisation of their devices from concept phase all the way up to quarter scale testing in Galway Bay. A provision of the joining of these actors into the same network, and the ability of the developers to access the knowledge base, facilities and public funding made available through the HMRC is the adherence to the HMRC's own protocol for development. This provision comes from a higher level- the SEAI which is tightly connected to the Irish government. The government is an entity which changes every four years and varies in its level of support. This was clearly evident when the Green Party used a €26 million boost to the wave energy sector as a means of pushing their own programme for government. Above this sits the EU, with overarching legislation and large pots of money.

Callon refers to 'enemy forces' (Callon, 2007, p: 66) in an actor-network which can prevent the successful realisation of what the actors in a network wish to achieve. As we can see from the empirical findings of this thesis, the main ‘enemy force’, as defined by the actors themselves, is the wider economic climate. The collapse of the Irish financial system has had a direct effect on investors, another key actor in this network. Investor confidence and public funds are both directly affected by the financial crisis and this has seeped into the very soul of the vulnerable wave energy sector, directing the course of technological development and, in the case of Wavebob, causing death.

An improvement of the economic climate in Ireland would give a big boost to the wave energy sector. As mentioned before, public and private investment is crucial if developers are to succeed. Since 2008, this has become a huge struggle and has played a central role in the demise of Wavebob who cite the lack of government support as one of the main reasons for this. If the economy was healthier and credit more readily available, investors would be more willing to take risks in projects like these which still have a large degree of uncertainty attached to them. The Irish state has been crippled by a fiscal crisis since 2008 which has resulted in huge budget cuts affecting sectors throughout the country. As the ANT analysis for this thesis has shown, this has affected the very nature of technological development, policy and protocol in Ireland. A more confident and consistent public investment in the wave energy sector would send a signal to private investors that they are putting their money into a well-structured and well-supported area.

In addition to this, the use of ANT’s holistic approach has shown that there are other constraints at play in this network. To begin with, even though most actors have said that the political situation in Ireland is satisfactory in its level of support, the role played by the Green Party during its time in government showed that more political support, and the establishment of positive mechanisms, can provide the framework for the sector to progress, strengthening other links in the actor-network. As we have seen, the gradual erosion of the OEDU has slowed the basic public administration of wave energy in Ireland, much to the frustration of one developer. This has occurred as a result of a gradual diminishing of interest in the sector, something which could be averted through a government more interested in the opportunities that wave energy might provide.

Secondly, the HMRC's protocol could be addressed. Although this is not an 'enemy force', in its strictest interpretation, its position of influence is such that any failings within it have massive effects on technologies as they try to emerge. Weber and Costello's TRL/TPL concept is a direct criticism to the way in which devices are developed. As previously mentioned, this calls for more flexibility in the evolution of devices at an early stage, particularly in taking holistic economic considerations into account when plotting the long-term course of development. This is, effectively, a call for the identification and integration of social factors into WECs from as early a stage as possible, a recognition of wider links in the actor-network. Despite the adherence and belief in the HMRC's protocol by Ocean Energy they, as the leading developer in Ireland, have followed Weber and Costello's path, even if this has not been explicitly stated. Instead of approaching development with a concept and patent, like most others have (including Wavebob), Ocean Energy started off with a blank page, taking the technological path which was pragmatically seen to fit in most with its social realities. This has enabled more flexibility and malleability along the way. Even though it has not been empirically proven in the investigation of this thesis, a lack of this kind of strategy could be the main reason for the collapse of Wavebob. By directing developers away from purely technological paths, and encouraging them to be more pragmatic and flexible, like Ocean Energy, a revised protocol could lead to more socially and economically ready machines and a much richer tapestry of technologies in Ireland for investors to choose from.

In summary, the use of an ANT analysis has shown that there are several important links in the Irish wave energy actor-network and that the success of this network depends on how strong these links are. Although the economy is seen by most actors as the big problem, it is the way that it has been allowed to slow down other actors, and weaken other links in the actor-network, that has hindered this sector. A successful realisation of wave energy in Ireland will depend on all actors in the network- politicians, developers, machines, economics, and protocol- co-existing in a positive way.

Wave Energy and ANT: Testing the Waters

As previously mentioned, one of the goals of this thesis is to see what the empirical findings from the Irish wave energy sector will tell us about ANT and other theories from the field of STS. Two main aspects of ANT, which are connected, will be examined in light of findings from the Irish wave energy sector:

- The theory that there are no boundaries between science, technology and the wider society and that these entities are affecting each other in a constant, multi-directional way, otherwise known as 'co-production.'
- The rejection by ANT of SSK's 'causality' from the unexplainable, wider society.

Co-Production

As mentioned, theory behind ANT and co-production rejects the view that some entities exist by themselves, independent of other forces in society. There is no science on the one hand and politics and economics on the other. Everything is linked together and plays a part in the production of the other entities. In light of this, an examination of the different entities within the wave energy sector is a good way to test this theory. It would be easy to demarcate between technology, politics and finance but wave energy in Ireland has shown that these boundaries are not so easily drawn. The role played by the HMRC's protocol would seem to demonstrate this.

Because investment is the ultimate goal for SME developers, this is taken into account from an early stage in the protocol. Weber and Costello's TRL/TPL concept aims to go even further than this but either way it is clear that economics, financing and investment play a performative role in the development of devices from an early stage. As devices develop, one of the reasons behind their quarter-scale dimensions is stated in the HMRC protocol as a means of attracting investors and having something concrete and appealing to show them. It is not enough to follow a purely technological path as this is not something the non-engineer investor can relate to. Instead, something on a larger scale which is in the water and visibly carrying out the job that it is built for is required. This should result in the realisation of funds from the investor and new life will then be breathed into the device, the investment enabling it to grow into a full-scale model on the path towards commercial development. This shows that as well as the entities of technology and finance being intertwined, the way that the HMRC protocol is written is a means of exploiting this.

The ANT analysis has also demonstrated a lack of boundaries between technological and political entities. To begin with, the boost that the Green Party gave to the sector in 2008 was, in many ways, a result of the previous actions of Ocean Energy, Wavebob, the SEAI and the HMRC. An already established sector provided the Green Party with something to cling onto in realising its own political goals. The manifestation of this was more financial support, the planned expansion of facilities for wave energy and an overall greater level of confidence in the sector.

The lack of boundaries between political and technological entities also affected the course of technological development for the OE Buoy. During the EU CORES programme, it was the use of the OE Buoy for the testing of separate, on-board, devices that showed its developers the attraction of these new technologies, leading to their ultimate adaptation to the WEC. This situation was created because of the previous close relationship between Ocean Energy and the HMRC, which played the role of the central institution in the CORES project and recruited the OE Buoy for the project. In addition, the quarter-scale OE Buoy was a production which owed its existence to Ocean Energy's adherence to the HMRC protocol and this was subsequently seen as a technological configuration perfect for the EU CORES project. As well as the OE Buoy benefitting from this arrangement, the various developers of peripheral devices for WECs across Europe have benefitted, some of them becoming partners with Ocean Energy. It could also be argued that the EU, in general, has been affected by this arrangement as the OE Buoy has provided it with knowledge about how to harness energy from the waves. This means that the EU is changed for the better and its citizens could ultimately benefit if this knowledge plays a role in the emergence of a valuable source of energy.

On the flip side, the shrinking of the OEDU from 4 full time members- focused solely on wave energy- to one on a partial basis shows how the interaction of entities can have a negative effect. A slowing down of activities in the wave energy sector in recent years, something partly attributable to other factors such as economics, has led to a lesser workload for those in the OEDU. This has, in turn, resulted in the gradual shrinking of the unit which has led to slower bureaucracy. This has slowed down response times for things like grants and applications which has, in turn, delayed the pace at which developers can engage in their projects. This gradual erosion cannot be directly attributable to one actor but is, instead, the consequence of a series of interactions within the actor-network which have weakened the overall strength of that network.

These examples show that there is truth in ANT's rejection of boundaries and, particularly, in its assertion that the best way of explaining entities is to focus on the specific interactions between those entities that create a network. The Irish wave energy sector shows, in part, that technology, politics and finance are simultaneously 'producing' each other and that to separate these entities is to overlook the real forces that create them. However, this suggests that there is no macro-force at play and that is something requiring further discussion.

Causality

It has already been mentioned several times in this thesis that the wider economy, and all the disadvantages which that brings, is something which central actors have cited as one of the major things holding back the development of WECs in Ireland. From an STS perspective, this takes a step away from ANT theory. Even though this thesis has limited its empirical focus to those actors directly involved in the wave energy sector the implications of the Irish financial collapse have been continually referred to by actors. Unlike investors, funding agencies, developers and politicians, this is not a force at play on a micro level in the wave energy sector. Even though ANT rejects distinctions between the micro and macro, it does focus on micro-links between entities and this presents some problems when analysing the relationship between the Irish wave energy sector and the larger economy.

One of the ways in which ANT took a turn away from SSK was in saying that wider social forces had to be explained. This was something already identified by Bloor when he referred to ‘settled and routinized institutions’, a point which we have already seen is very similar to Law’s ‘punctualized resources’. An in-depth explanation of how the ‘network’ that is the Irish economy was formed is beyond the scope of this thesis. If we wanted to, we could talk about the Irish banking regime, property developers, corrupt politicians and poor regulation, show the links between them, and come to the conclusion that these are all at play in the forming of the complex network that is the Irish economy. As mentioned, this is a point not lost on ANT- these forces are ‘punctualized’ and that is satisfactory enough.

What is important to observe is that, in this case at least, the power of some ‘punctualized resources’ only goes in one direction. Counter to ANT theory, the Irish economy exists as a powerful macro force in relation to the wave energy sector, taking power away from the micro-network as it dictates much of the wave energy sector’s path. This brings the analysis of this thesis back to early SSK theories of Bloor and Collins where a clear causality flows from the Irish economy to the development of wave energy in Ireland, a force which in recent years has been negative. Bringing this in line with a focus on micro-links, as ANT recommends, would probably entail, for example, looking at the agent within the SEAI who played the role of denying Wavebob its €10 million in funds. However, this would still bring the examination back to the economic forces detailed above.

This unidirectional relationship could, of course, change in the future. The successful emergence of a company like Ocean Energy could result in the deployment of large arrays of WECs off the west coast of Ireland. The result of this would be more indigenous energy to the Irish grid and potentially more jobs from a new manufacturing sector, both of which would have a significant effect on the Irish economy. However, this is not the reality of the present where no real industry has emerged from the wave energy sector and, thus, no effects on the Irish economy can be felt. As things are at the moment, the wave energy sector receives whatever framework the Irish economy presents and adapts to those circumstances.

Finding a Compromise

In light of these findings, within what theoretical framework do we place the Irish wave energy sector? As we have seen, the linkages between technology, protocol, investors, institutions and politics create a web of multi-directional effects, mainly in line with ANT and co-production. In tandem, SSK deductions of external causality are also hard to discard, particularly when recognising the massive effect that the Irish economy has had on the sector.

A good explanation would appear to come from another source. Geels talks about the 'multi-level perspective' when addressing technological transitions (Geels, 2002, p: 1261). According to Geels, technologies are set in a 'socio-technical landscape' which refers to the larger, hardened society. This landscape changes but does so slowly, in its own way and independent of whatever happens in the technological network which resides below it:

"The socio-technical landscape contains a set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems. The landscape is an external structure or context for interactions of actors. While regimes refer to rules that enable and constrain activities within communities, the 'ST-landscape' refers to wider technology-*external* factors." (Geels, 2002, p: 1260)

Most relevant to this thesis is the observation that technologies are 'embedded' in a wider regime which will dictate much of that technology's development. Importantly, the effect is unidirectional and any changes which occur in that wider landscape are, on the whole, a result of many other forces, some of which have been named above. In light of findings from the Irish wave energy sector and the co-existence of theories from SSK and ANT, this theory from Geels fits well.

Conclusion

This thesis has attempted to use tools and concepts from ANT and STS, in general, to find an answer to how Ireland can successfully implement wave energy. On a parallel level, it has strived to use the empirical findings from the Irish wave energy sector to address some of the theoretical frameworks mentioned above.

In conclusion, it is clear that the Irish wave energy sector still has some way to go before it can fully emerge as a genuine player in the Irish energy mix. With only one real hope for an indigenous technological device, questions must be asked over whether technological paths are well chosen. Ocean Energy have shown that flexibility and adaptability are crucial if a device like this can fit in with the society it is trying to have an effect on. This is a belief reinforced by consultation with Weber and Costello and their alternative protocol. A following of this path by more developers could enrich the market in Ireland. However, this will have to happen in a much healthier economic climate if wave energy is to have any real chance of taking off. In addition, examinations of this thesis have shown that a government positively and actively inclined to an industry like this will provide the framework for its positive implementation. A repeat of the policies and enthusiasm of the Green Party's time in government would be a major boost to wave energy in Ireland.

Theoretically, wave energy has shown us that there is still some debate around differing perspectives offered by SSK, ANT and STS, in general. While analysis from this thesis has shown that co-production and multi-directional agency are prevalent, it is also clear that unidirectional causality is still a factor in analysing technological objects. It is, thus, the contention of this thesis that these theories don't necessarily have to be a rejection of each other but that they can be simultaneously applied when analysing technological systems.

By using an ANT framework and by following its methodological practices, this thesis has identified the main actors within the wave energy sector in Ireland and followed them in unlocking the puzzle within that sector. Information was garnered through an extensive literary review which was then followed up by a series of interviews. Based on the fact that research for this thesis was limited to a six month window, it is the opinion of this writer that a longer and more extensive investigation would lead to deeper and more comprehensive findings. Central to this could be more interviews, particularly with more than one developer in Ireland as well as actors connected to the current government and those directly responsible for wave energy within the SEAI. Follow up interviews with some of the actors appearing in this paper would also provide some more valuable insights, particularly in light of information garnered after their interviews. It would also be interesting to use ANT in taking the topic of wave energy to a wider, more international level, starting with the sector in the United Kingdom. A comparison between the Irish system and that of another country would be valuable in learning different perspectives and also in learning different strategies to technological paths in particular. This would also be useful in highlighting the positives and negatives of the Irish sector.

Overall, it must be concluded that, despite the many problems it faces, wave energy does have a future in Ireland and some mechanisms are in place for the emergence of this sector. As this thesis has attempted to show, social, economic, political and many other forces will ensure that there are still many turns in the road ahead.

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